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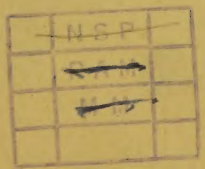

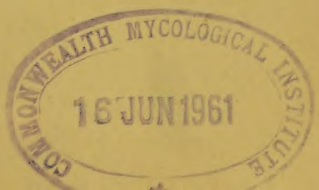

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Titles should be as brief as possible.

Units of measurement should be placed in parenthesis at the head of the column, not in the body of the table. Descriptive notes should be kept to the minimum, and abbreviations used wherever possible. For abbreviations, etc., the usage followed is that of British Standard 1991, Letter Symbols, Signs, and Abbreviations. Part 1. General.

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THE YIELD AND ENERGY CONTENT OF MILK AND THE ENERGETIC EFFICIENCY OF SOWS ON DIFFERENT LEVELS OF NUTRITION DURING GESTATION AND LACTATION

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(*Received for publication, 12 May 1960*)

Summary

The results of an experiment to determine the effects of different levels of nutrition during gestation and lactation upon sow milk yield and composition, and the energetic efficiency of litter production, are presented.

As a preliminary to the main experiment, 20 sows were subjected to a low level of nutrition over a full reproductive cycle in an attempt to deprive them of all body reserves.

The yield and composition of the milk of 10 of these sows were recorded during the depletion cycle. The average milk yield and energy yield per sow were relatively low—492 lb and 338 therms, respectively. The mean fat test was extremely high—10.8%, and the lactose content was low—4.1%. The gross efficiency of milk production was 52%.

As a result of deaths due to the severity of the treatment imposed, and failure to get a number of sows in pig following the depletion cycle, only 12 of the original 20 sows were available for the experiment proper.

The treatments imposed on these sows during gestation and lactation were as follows:—

(i) High-Low: Gestation high, Lactation low.
(ii) Low-High: Gestation low, Lactation high.
(iii) Low-Low: Gestation low, Lactation low.

The mean milk yield per sow and per piglet for the three treatments were: High-Low—657 lb and 68 lb; Low-High—761 lb and 82 lb; Low-Low—579 lb and 66 lb. The difference in yield between the High-Low and Low-Low groups was not significant. The difference between the yields of the combined High-Low and Low-Low groups and those of the Low-High groups was statistically significant.

Gross energy per pound of milk and mean fat tests were: High-Low —633 kcal, 9.6%; Low-High—550 kcal, 7.5%; Low-Low—603 kcal, 8.7%. The fat test of the combined High-Low and Low-Low groups was significantly higher than that of the Low-High group.

The mean milk energy production figures per sow and per piglet for the three treatments were: Low-High—418 therms* per sow, 45.1 therms per pig; High-Low—415.6 therms per sow, 43 therms per pig; Low-Low—349 therms per sow, 39.7 therms per pig. The differences in energy production were not statistically significant.

The data suggest that the high fat content *per se*, or, alternatively, the relatively low crude protein content per 1,000 digestible calories, of the milk of the sows on the High-Low and Low-Low treatments, resulted in reduced weight gains and lower efficiency of energy conversion by their litters compared with those of the Low-High treatment sows, over the first 4 weeks of lactation.

The sows which received low rations during lactation used the energy available from their feed and from the catabolism of body reserves more efficiently than those on a high ration. On the other hand, the energy recovery in the form of sow and litter tissue energy from feed energy invested over lactation and gestation was greater for the sows fed on a high ration.

It is concluded: (a) that the practice of building up sow body reserves during gestation and dissipating these during lactation is energetically inefficient; (b) that high energetic efficiency can be achieved only where sows are fed to gain weight throughout both gestation and lactation.

The application of these results to pig farming practice is briefly discussed.

INTRODUCTION

In a previous experiment carried out at this Station (Smith 1960), an attempt was made to measure the effect of the condition of the sow at the time of farrowing upon the level and efficiency of milk production during the subsequent lactation. The results of this experiment were not conclusive because the sows which farrowed down in low condition lost more weight during lactation than they had gained during gestation, indicating that they had, in fact, possessed appreciable body energy reserves at the time of mating. It was evident that to conduct such an experiment satisfactorily, the experimental animals should, if possible, be deliberately depleted of all body reserves prior to the application of any experimental treatments. The experiments reported here, therefore, cover two reproductive cycles—the first, a depletion cycle, and the second (the experiment proper) one in which various ration levels were imposed during gestation and lactation.

EXPERIMENTAL METHODS AND MATERIALS

The general plan of the experiment was as follows:

(1) To deplete severely the body reserves of a group of sows in the course of a reproductive cycle, by subjecting them to a low plane of nutrition during gestation and lactation.

(2) Then to divide the group into two sub-groups following remating, one group to be fed on a high plane and the other on a low plane during gestation.

(3) To divide each of the sub-groups into two further groups at farrowing, one to be fed on a high, the other on a low, plane of nutrition during lactation. This final subdivision would then result in the following treatments.

* One therm = 1,000 kilocalories.

Gestation	*Lactation*
(a) High Plane	High Plane (High-High)
(b) High Plane	Low Plane (High-Low)
(c) Low Plane	High Plane (Low-High)
(d) Low Plane	Low Plane (Low-Low)

(1) The Depletion Cycle

Twenty sows, consisting of 10 pure-bred Berkshire, all of which had previously farrowed at least one litter, and 10 first-litter Large White Berkshire sows, were selected for the experiment from a group of 30 which were available for autumn mating. In order to reduce the spread of farrowings to a minimum the sows finally selected were those that had been successfully mated within a period of 14 days.

All sows were individually fed six gallons of milk daily for the first three weeks after mating to ensure that they would exhibit heat at the normal time, if they had failed to conceive at the first mating. The ration was then reduced to four gallons per day for three weeks.

During the period from the sixth to the 13th week of gestation, pasture was the only source of feed. Each sow was individually housed three weeks prior to farrowing and received three gallons of milk daily in addition to pasture. The ration during lactation consisted of three units of feed per sow and one half unit for each piglet suckled, one gallon of milk or one pound of concentrate (three parts barley-meal, one part meat-meal) being considered as a feed unit. The yield and composition of the milk of the 10 Berkshire sows were recorded and the data are presented later in this paper.

(2) The Condition of the Sows at the End of the Depletion Cycle

Two sows, one Berkshire and one Crossbred, failed to respond when fed an increased ration after weaning, and both died within a week. The remaining 18 sows were in very low condition and were remated at the first heat after weaning. Twelve finally conceived, the remaining six either failed to exhibit oestrus or returned to the boar at regular three-weekly intervals. Because of this difficulty, the first 10 sows which appeared to be safely in pig were allotted to the low-plane group, the remainder being placed on a high plane of nutrition in an attempt to stimulate normal oestrus and secure a successful mating. Only three of these eight sows finally conceived; three others appeared to be satisfactorily mated but returned to the boar 12 weeks after service, while two returned to service regularly at 21-day intervals. In addition, one of the 10 low-plane group subsequently proved to be empty. As a result, the experiment proper consisted of three groups of unequal size, and the High-High treatment was entirely discarded.

(3) The Experiment Proper

After mating, following the depletion cycle, the sows received six gallons of milk per day for 28 days in an attempt to stimulate oestrus in any animal not pregnant. Subsequently, the rations were adjusted each week after the sows were weighed, the aim being to produce a gain of $2\frac{1}{2}$ lb per week on the low plane, and 7 lb per week on the high plane, sows. During lactation, the low plane sows received three units of feed

per sow plus one half unit per piglet, while those on the high plane received six units per sow plus one unit per piglet suckled. The general management of the sows and litters, the techniques used in determining the yield and composition of milk, and the methods involved in calculating the energetic efficiency of production, have been described in previous papers in this series (Smith 1959a, b and 1960).

RESULTS

The Depletion Cycle

The data relating to the 10 Berkshire sows whose productions were recorded over the depletion cycle are presented below and briefly discussed. The gestation intakes shown include the estimated energy intake from pasture.

TABLE 1. THE GESTATION FEED-ENERGY INTAKE AND THE WEIGHT CHANGES OF THE 10 BERKSHIRE SOWS OVER GESTATION AND LACTATION OF THE DEPLETION CYCLE

Sow No.	Feed Energy Intake (therms) †	Wt. At Mating (lb)	Wt. After Farrow (lb)	Gain (lb)	Wt. At Weaning (lb)	Loss (lb)
127	841	270	319	49	269	50
128	745	249	285	36	238	47
122	795	288	320	32	290	30
*121	875	274	323	49	265	58
120	783	376	384	8	345	39
*119	702	271	298	27	253	45
‡117	757	305	324	19	299	25
107	1032	365	422	57	357	65
102	782	327	344	17	312	32
*106	818	361	381	20	319	62
Means	813	308.6	340	31.4	294.7	45.3

‡ Died soon after weaning.
† One therm = 1,000 kcal.
* Failed to re-breed.

Records of the weight gains of a large number of gestating sows which farrowed down in what was considered at this Station as ideal condition, provide values with which the above gains may be compared (Smith 1960). On the average, sows carrying their third litters gained 110 lb while older sows gained 70 lb. The sows whose records are shown in Table 1 were either carrying their third litters or were older, and had been on a low plane of nutrition during their previous lactation. They were, therefore, in low condition at mating and little better at farrowing. The production records are shown in Table 2.

The average number of pigs farrowed and weaned by Berkshire sows at this Station over a period of five years, including the period of this experiment, was nine and seven respectively. As a group, the depleted sows exceeded these averages despite the low level of nutrition to which they were subjected. This failure to depress litter size by the imposition of severe nutritional treatment during gestation is in line with the findings of Ballinger (1944), and King and Young (1957).

TABLE 2. THE NUMBER OF PIGS BORN AND WEANED AND THE YIELD AND COMPOSITION OF MILK FROM 10 BERKSHIRE SOWS OVER THE DEPLETION CYCLE

Sow No.	No. Born	No. Weaned	Milk Yield (lb)	% Fat	% Prot.	% Lact.	Milk Energy (therms)
127	7	7	447	10.2	5.9	4.2	293
128	8	8	485	11.5	6.2	3.9	344
122	11	10	488	9.9	6.2	4.4	319
121	10	9	501	11.2	6.3	4.2	353
120	13	11	469	11.2	6.7	4.0	334
119	10	10	469	11.8	6.4	4.0	342
117	15	9	468	10.0	6.2	4.2	307
107	11	8	523	9.7	6.0	4.3	333
102	11	10	569	12.4	6.6	3.8	431
106	13	9	506	9.8	5.9	4.4	324
Means	10.9	9.1	492.5	10.8	6.2	4.1	338

Other points of interest arising from the data in Table 2 are the high fat content of the milk and the low lactose content. The fat content of 10.8% was higher than any previously recorded in this series of sow nutrition experiments, while the lactose content of 4.1% was the lowest. In addition, the energy content of the milk (686 kcal/lb) was considerably above any value obtained in earlier studies. The highest previous value was 653 kcal/lb from a group of sows fed on a similarly low ration during lactation (Smith 1959b).

The estimates of production efficiency calculated by two methods as outlined in a previous study (Smith 1960a) are shown in Table 3.

TABLE 3. ESTIMATES OF THE ENERGETIC EFFICIENCY OF GESTATION, LACTATION AND THE WHOLE REPRODUCTIVE CYCLE, OBTAINED BY TWO METHODS OF CALCULATION: (A) SOW WEIGHT CHANGES RELATED TO SOW INTAKE, (B) SOW WEIGHT CHANGES RELATED TO LITTER ENERGY

	Energetic Efficiency			
Gestation	Lactation	Lactation Less Creep	Reproductive Cycle	Reproductive Cycle Less Creep
Method A 1.59%	31.3%	24.7%	18.6%	13.3%
Method B 14.1%	18.5%	5.52%	16.25%	10.5%

The estimates are of the same order as those obtained in earlier studies. The gross efficiency of milk production was 52%, which was similar to the values obtained from the three previous groups of sows fed on low rations during lactation, namely, 53%, 53%, and 54%. Similarly, the efficiency of energy utilisation over the whole reproductive cycle, excluding the effect of creep feeding, for these same three groups, was 12.5%, 13.0%, and 13.25%.

The Experiment Proper

The final allotment of sows to the three treatments, together with their liveweight records over the depletion cycle, are shown in Table 4.

TABLE 4. THE LIVEWEIGHT RECORDS OF THE SOWS OVER THE DEPLETION CYCLE AND THE EXPERIMENTAL TREATMENTS TO WHICH THEY WERE ALLOCATED

Final Treatment	Sow No.	Wt. At Mating (lb)	Weight After Farrow (lb)	Wt. At Weaning (lb)
High-Low	131	254	346	273
	132	253	280	243
	128	249	285	238
Means		252	303	251
Mean gain or loss		+ 51	— 52	
Low-High	129	250	297	271
	130	260	330	257
	127	270	319	269
	102	327	344	312
Means		277	322	277
Mean gain or loss		+ 45	— 45	
Low-Low	133	262	325	282
	134	259	309	268
	122	288	320	290
	120	376	384	345
	107	365	422	357
Means		310	352	308
Mean gain or loss		+ 42	— 44	

Three sows, Nos. 131, 129, and 133, all first-litter sows, were appreciably heavier at the end of the depletion cycle than at the beginning. These animals, in common with the remainng sows of the same age, Nos. 130, 132 and 134, made substantial skeletal growth during the cycle while obviously losing condition. The weight differences shown, therefore, are not a true indication of the state of emaciation to which these and the remaining sows were reduced at the end of the depletion treatment.

The feed energy intakes during gestation and lactation, and the weight gains of the three groups of sows over the experiment proper, are shown in Table 5. The gestation intakes include the estimated feed energy derived from pasture.

Two of the sows on the Low-Low treatment, Nos. 107 and 120, lost substantially more weight during lactation that they had gained during gestation. Apparently the depletion cycle was not severe enough to rob these particular animals of all their mobilisable reserves, the presence of which could not have been suspected from their appearance at mating. Sow No. 107 had been subjected to a low plane of nutrition in the course of an experiment immediately prior to the depletion trial. She was in low condition at the time of farrowing at the commencement of that experiment and lost 43 lb more than she had gained during gestation. During the depletion trial she lost 8 lb more during lactation

TABLE 5. THE ENERGY INTAKES AND WEIGHT CHANGES OF THE SOWS DURING GESTATION AND LACTATION

(Energy values in therms)

Sow No.	Feed Energy Intake Gest.	Gest. Wt. Gain (lb)	Feed Energy Intake: Lact. (8 Weeks)	Lact. Wt. Change (lb) (8 Weeks)	No. Of Pigs Suckled
Treatment High-Low					
131	1269	118	713	—39	13
132	1176	111	592	—49	10
128	1191	110	456	—68	6
Means	1212	113	587	—52	9.7
Treatment Low-High					
129	879	51	1238	+26	12
130	884	59	1073	—16	8
127	817	43	1102	+20	10
102	827	31	932	+ 1	7
Means	851.7	46	1086	+ 7.7	9.2
Treatment Low-Low					
133	966	62	612	—62	10
134	959	66	658	—64	12
122	855	46	602	—28	10
120	891	39	332	—52	3
107	878	29	557	—68	9
Means	909.8	48	552	—54.8	8.8

than she had gained during gestation. In the experiment proper her loss over the cycle was 39 lb. This sow had, therefore, lost 86 lb over three reproductive cycles despite the fact that she appeared to be in poor condition at the commencement of the period.

In view of the extent of their reserves, the High-Low plane sows might have been expected to have lost more weight than the Low-Low group. It is possible that a proportion of the weight gains made by all the sows during gestation was due to replacement of protein tissue catabolised during the depletion cycle, and that some of the weight lost during lactation by the Low-Low group was the result of the re-catabolism of muscular tissue to provide the necessary energy supplement to the low rations fed. This point will be discussed more fully later.

The yield and compositon of the milk of the three groups are shown in Table 6.

The effect of stage of lactation upon the yield and composition of the milk of the three groups is shown in Fig. 1.

The data shown in Table 6 indicate that the milk yield of the Low-High group was substantially greater than that of the High-Low animals, which in turn yielded more than the Low-Low group. After adjusting for litter size it was found that the Low-High treatment yields were significantly greater ($P = .02$) than those of the other two treatments which did not differ significantly. There was no significant difference between treatments in regard to milk energy production, but the fat

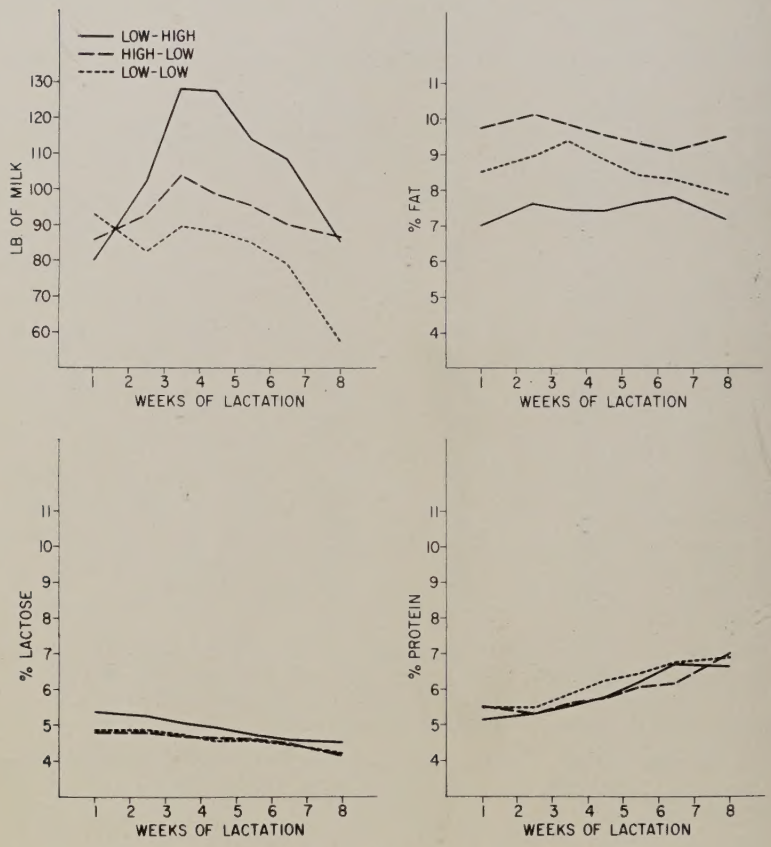

Fig. 1.—The effect of stage of lactation upon the average yield and composition of the milk of the sows on the three treatments.

test of the Low-High group was significantly lower than that of the remaining two groups, which, again, did not differ significantly.

Litter Growth and Creep Intake

As shown in Table 7, the weight gains of the piglets from the three groups did not reflect the differences in the milk yield or the milk energy yields of their dams. The sow milk energy intakes of the litters shown in this table were calculated by subtracting the energy contained in the samples withdrawn for analysis from the total milk energy produced. For this reason the milk energy intake per piglet differs slightly from the yield per piglet shown in Table 6.

TABLE 6. THE YIELD AND COMPOSITION OF THE MILK OF THE SOWS IN THE 3 GROUPS

Sow No.	Milk Yield (lb)	Milk Energy (therms)	Fat (%)	Protein (%)	Lactose (%)
Treatment: High-Low					
131	763	471	9.2	5.7	4.8
132	699	441	9.6	5.7	4.7
128	509	335	10.1	6.2	4.4
Mean/sow	657	415.6	9.6	5.8	4.6
Mean/piglet	68.0	43.0			
kcal/lb milk	633				
Treatment: Low-High					
129	925	487	6.7	6.0	5.0
130	591	365	9.3	5.5	4.9
127	795	416	6.7	5.9	4.9
102	732	404	7.3	6.2	4.7
Mean/sow	760.7	418	7.5	5.9	4.9
Mean/piglet	82.3	45.1			
kcal/lb milk	550				
Treatment: Low-Low					
133	610	376	9.1	5.9	4.6
134	810	495	9.0	6.0	4.5
122	547	317	8.0	6.4	4.6
120	229	141	8.9	6.2	4.6
107	698	417	8.5	6.1	4.7
Mean/sow	578.8	349.2	8.7	6.1	4.6
Mean/piglet	65.8	39.7			
kcal/lb milk	603				

TABLE 7. THE ENERGY INTAKES AND WEIGHT GAINS OF THE LITTERS

Treatment	High-Low	Low-High	Low-Low
Sow milk energy intake: therms per piglet	40.9	42.9	37.7
Creep energy intake: therms per piglet	25.3	22.3	33.0
Total	66.2	65.2	70.7
Weight gain per piglet	25.7	29.0	28.6
Therms per lb gain	2.57	2.25	2.48

As was found in previous studies (Smith 1959a, b, 1960) there was an inverse relation between milk energy yield and creep energy intake; the litters which obtained the least energy from sows' milk consuming the greatest amount of creep. A point of interest is that the litters of the two groups of sows on the low plane of nutrition during lactation required more feed energy per pound of gain than the litters of the Low-High sows.

Estimates of Energetic Efficiency

The gross efficiencies of milk production for the individual sows are shown in Table 8. The data in this table relate to the last seven weeks of the lactation. It will be noted that the energy equivalent of the sow weight changes was calculated from the weekly weight changes. On this basis gains made in any particular week were credited with 4,925 kcal/lb, while losses were debited at 3,312 kcal/lb. The final values shown are the sums of the energy contents of these changes.

TABLE 8. THE GROSS EFFICIENCIES OF MILK PRODUCTION OF THE SOWS ON THE 3 TREATMENTS (Energy values in therms)

Sow No.	Loss Or Gain In Weight (lb)	Energy Equiv. Of Wt. Change	Feed Energy Intake	Total Energy Intake Equiv.	Milk Energy Yield	Gross Efficiency (%)
Treatment: *High-Low*						
131	—39	+121	628	749	471	62.9
132	—44	+146	520	666	441	66.2
128	—55	+182	394	576	335	58.2
Mean per sow	—46.0	+149.7	514	663.7	415.7	62.4
Treatment: *Low-High*						
129	+22	—112	1157	1045	487	46.6
130	—23	+ 70	972	1042	365	35.0
127	+12	— 64	1028	964	416	43.2
102	— 3	+ 2	844	846	404	47.7
Mean per sow	+ 2.0	— 26	1000.2	974.2	418.0	43.1
Treatment: *Low-Low*						
133	—49	+162	520	682	376	55.1
134	—44	+143	584	727	495	68.1
122	—24	+ 73	521	594	317	53.4
120	—48	+159	292	451	141	31.3
107	—59	+195	487	682	417	61.1
Mean per sow	—44.8	+146.4	480.8	627.2	349.2	53.8

As was found in a previous study (Smith 1959b), the sows on the lower rations during lactation used their feed for milk production more efficiently than those on the high ration. The actual values obtained in the present study are, however, much higher than those obtained previously. The efficiency shown for the Low-Low group could be an underestimate of the true value. If, as suggested earlier, a proportion of the weight loss incurred by the sows in this group was due to protein rather than fat catabolism, the energy value of each pound of loss would be less than 3,312 kcal (Smith 1959a). As a result, the true gross efficiency would be somewhat higher than that shown.

The gross energetic efficiencies of milk and litter production for the seven weeks of recorded lactation are shown in Table 9.

The energetic efficiencies of the sow groups and their litters, by weeks, are shown graphically in Fig. 2.

TABLE 9. GROSS EFFICIENCY VALUES FOR MILK AND LITTER ENERGY PRODUCTION FOR THE LAST 7 WEEKS OF LACTATION*

Treatment	High-Low	Low-High	Low-Low
Gross efficiency of milk production (weighted means)	63%	43%	56%
% of sow and creep feed energy recovered in litters	30.3	25.0	30.2
% of sow feed energy equivalent recovered in litters	26.3	20.4	24.1
% of sow milk and creep feed energy recovered in litters	43	48	44.6

* Calculations based on formulae developed in previous paper (Smith 1960).

Fig. 2a, the sow feed energy intake equivalent per therm of milk energy produced, indicates that the ranking order shown in the last column of Table 8 holds true for each week—the sows on the lower rations during lactation, High-Low and Low-Low, being more efficient than the Low-High group.

Fig. 2b, summarising the litter intake of metabolisable energy, from sows' milk and creep, per pound of liveweight gain, warrants further comment. As shown in Tables 7 and 9, the litters of the sows on the High-Low and Low-Low treatments were less efficient feed energy converters than the litters of the sows on the Low-High treatment, when the efficiency was calculated for the whole seven weeks. It was also true that the litters of the High-Low and Low-Low groups consumed most creep feed. It might be suggested that the greater apparent energy requirement was not real, but was due to an overestimation of the energy content of the creep feeed, the litters which consumed the greatest quantity being most severely penalised. Fig. 2b indicates that the greatest difference in the feed conversion efficiency between treatments occurred in the second and third weeks of lactation when no creep was fed, and the fourth week when the creep intake was negligible. Once the litters started to consume appreciable amounts from the creep the three treatments achieved similar levels of efficiency. The slower growth and lower efficiency of the litters from the High-Low and Low-Low groups was not due to lower intakes of sow milk energy per piglet during the second, third and fourth weeks of lactation (Table 10). Over this period the feed energy available per piglet was similar for the three treat-

TABLE 10. THE CUMULATIVE SOW MILK ENERGY INTAKE PER PIG BY WEEKS
(Energy values in therms)

Weeks Of Lactation	2	3	4	5	6	7	8
Treatment:							
High-Low	5.5	11.4	17.9	24.0	29.8	35.3	40.9
Low-High	4.8	10.5	17.6	24.7	31.2	37.6	42.9
Low-Low	5.7	11.1	17.2	23.0	28.5	33.6	37.7

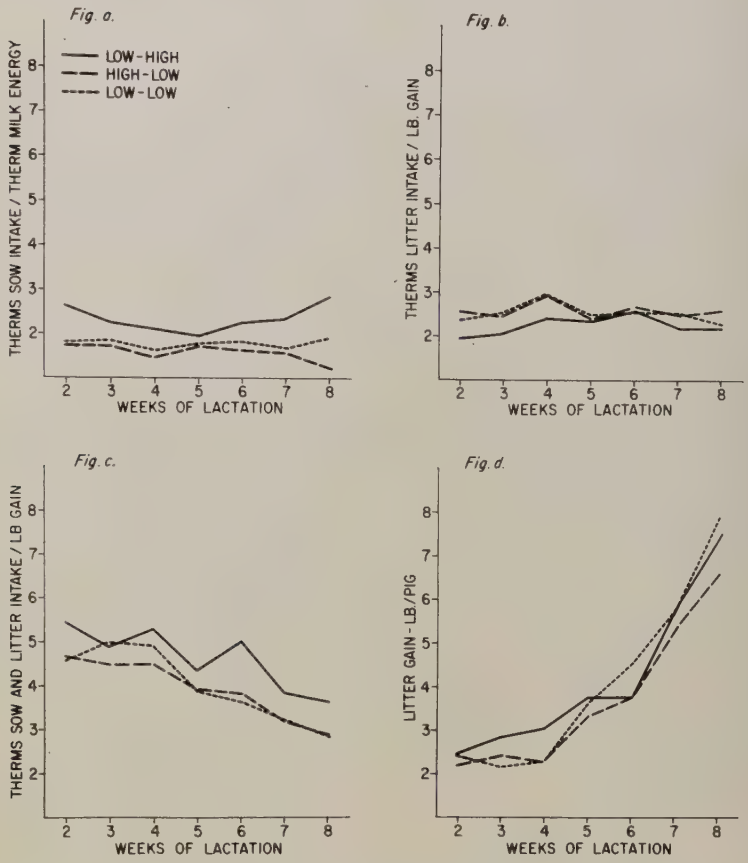

Fig. 2.—The effect of stage of lactation upon sow and litter efficiency.

(a) Therms of sow feed energy equivalent per therm of milk energy produced.

(b) Therms of sow milk and creep energy intake by the litter per lb of litter gain.

(c) Sow and litter feed energy equivalent intake per pound of litter gain.

(d) The mean liveweight gain per pig by weeks.

ments, any difference in the second and third weeks being, in fact, in favour of the High-Low group which gained least weight.

It may be significant that the lowest efficiency of conversion by the litters occurred over the period when the fat content of the milk was highest. After the fourth week, the consumption of creep feed, containing approximately 4% of digestible fat, would result in a drastic reduction in the overall fat content of the ration.

The depression in the growth rate and efficiency observed in the litters of both the High-Low and the Low-Low groups may be attributable to the high fat content *per se* (Catron *et al.* 1953) or to a serious widening of the protein energy ratio in the sows' milk. Lodge and Lucas (1959) have suggested that, for optimum growth, piglets between 3 and 10 lb liveweight require 60 g of crude protein per 1,000 digestible calories of intake, and that this protein requirement falls to 54 g between 10 and 20 lb, and to 43 g between 20 and 45 lb. The protein per 1,000 digestible calories, available to the litters in this study, is shown in Table 11.

TABLE 11. GRAMMES OF CRUDE PROTEIN PER 1,000 DIGESTIBLE CALORIES OF LITTER INTAKE BY WEEKS

Weeks of Lactation	Grammes Of Crude Protein Per 1,000 Digestible Cal.						
	2	3	4	5	6	7	8
Sow Treatments:							
High-Low	38	37	40*	49	58	65	71
Low-High	44	43	48	54	60	68	75
Low-Low	39	41	45	57	64	71	78
Suggested requirement (Lodge and Lucas)	62	62	54	54	43	43	43

* From the end of the third week the protein and energy contents of the creep intake have been included in the data.

It is evident that during the second and third weeks none of the three groups of sows produced milk containing the ratio of protein to digestible calories suggested by Lodge and Lucas, viz. 62 : 1.000. The discrepancy was greatest in the milk of the High-Low sows. Figs. 2b and 2d show that during the fifth week both the efficiency of energy conversion and the growth rate of the litters from the High-Low and

TABLE 12. COMPARISON OF ENERGETIC EFFICIENCIES

Treatment	Method A			Method B		
	Percentage Efficiency Of Energy Conversion					
	High-Low	Low-High	Low-Low	High-Low	Low-High	Low-Low
Period:						
Gestation	1.6	1.5	1.6	31.7	19.0	18.8
Lactation	29.6	25.4	29.3	15.1	26.6	14.1
Lactation less creep	25.9	21.2	23.7	4.2	23.7	—1.0
Reproductive cycle	17.7	17.5	17.5	25.0	23.6	16.5
Reproductive cycle less creep	13.8	13.8	12.5	22.8	21.1	11.2
Gross efficiency of milk production	63	43	56			

Low-Low groups improved, and, as shown in Table 11, this improvement coincided with an increased protein/energy ratio in the intake of the litters.

The Energetic Efficiency of the Reproductive Cycle

As in previous reports in this series (Smith 1960), the energetic efficiency of gestation, lactation, and the whole reproductive cycle has been calculated using two methods. Under Method A the energy recovered in litter tissue is expressed as a percentage of the feed energy intake equivalent of the sow and litter. In determining the "intake equivalent" of the sow, the energy equivalent of sow body-weight gains or losses are respectively subtracted from, or added to, the observed energy intake. Under Method B, the energy equivalent of sow body-weight gains or losses are respectively added to, or subtracted from, the energy recovered in litter tissue, and the resultant value is expressed as a percentage of the observed energy intake of the sow and litter. The values obtained by these two methods are shown in Table 12.

General Discussion

The effect of ration level upon milk yield shown in the present experiment is at variance with that found in a previous study (Smith 1959b), where daily rations of six feed units per sow and one per piglet suckled, were compared with levels of four plus two-thirds and three plus half. In this latter experiment there was a slight reducton in yield between the six plus one and four plus two-thirds levels in the one season, but no material reduction between four plus two-thirds and three plus one-half in the following season. The present study, where all treatments were being run simultaneously, has indicated that a reduction in ration level from six plus one to three plus one-half does, in fact, result in a significant drop in milk yield.

The conclusion that milk energy yield was not affected by ration level, which was reached in the previous study, was supported by the results of the statistical analysis of the data from this experiment. On the other hand, the relatively low milk and milk energy yields of the 10 Berkshire sows whose productions were recorded over the depletion cycle, together with the lower, but not significantly lower, yield of the Low-Low group in the experiment proper, suggest that sows with depleted body reserves do, in fact, exhibit a real drop in milk and milk energy production. It is also evident that sows in such condition will continue to milk until emaciated to the point of death. In both experiments lowered rations resulted in greater weight losses by the sows, with higher fat tests and higher energy yields per pound of milk.

The evidence advanced, that the wide protein/energy ratio of the milk of the sows on the low level of nutrition during lactation, was a possible cause of the low feed conversion efficiency and low growth rate of their litters over the first four weeks, if true, suggests that the practice of allowing sows to build up condition during pregnancy and dissipate this stored energy during lactation, is not only energetically inefficient in terms of the sow, but is actively detrimental to the litter. Various theories have previously been advanced at this Station to explain the very common phenomenon of reduced litter weight gains in the third

or fourth weeks of lactation, one being that such litters were suffering from a subclinical anaemia. This theory was recently tested by Crawley and MacDiarmid (1959), and, while it was found that the injections of iron dextran (Im feron) did enable the piglets to maintain a significantly higher haemoglobin level than untreated controls over the first four weeks, the growth rates of the treated and untreated animals were the same. There may be other factors than the protein energy ratio contributing to reduced growth rate over this critical period, but at the moment the evidence advanced by Lodge and Lucas (1959) appears the most convincing.

The estimates of energetic efficiency obtained from this study merit discussion in some detail.

The Energetic Efficiency of the Gestational Period

The values obtained under Method A are of the same order as those obtained in previous studies, and illustrate the small energy requirement for prenatal growth of the litter in comparison with that for maintenance. The values obtained by the second method of calculation emphasise the energetic inefficiency of a low level of feeding when this provides a meagre productive ration relative to maintenance requirements. Both groups which were poorly fed during gestation exhibited low energy return in comparison with the group that was fed on a high level (High-Low).

The Energetic Efficiency of the Lactational Period

It is apparent from the values obtained by Method A that the sows receiving low rations during lactation utilised the energy available from their feed and from their body reserves more efficiently than those fed above their requirements for maintenance and milk production. To some extent the values for lactation, including the effect of creep intake, unduly favour the poorly fed groups, since the litters from these sows consumed more creep feed than those from the well-fed sows. When the effect of creep feeding is excluded, however, the sows on low lactation rations still showed to advantage.

Under Method B, where sow weight losses are offset against the energy recovered in litter gains, the efficiency-ranking order obtained under Method A was practically reversed, the sows fed on low rations during lactation being less efficient than the Low-High group which did not lose weight. When the effect of creep feeding was excluded, the differences in energetic efficiency were accentuated.

It is evident that, while the sows fed on a sub-maintenance ration during lactation used the energy available to them more efficiently than those on a maintenance ration or higher, the final energy return from feed energy invested was greater when the animals were well fed than when poorly fed.

The Energetic Efficiency of the Reproductive Cycle

The values obtained under Method A for the whole reproductive cycle are of the same order as those for the depletion cycle and for previous studies, as reported earlier in this paper. The data in Table 12 show that when the effect of creep feeding was excluded, 13.8% of the

feed energy equivalent available to the High-Low and Low-High treatment sows was recovered as litter energy, while only 12.5% was recovered in the Low-Low group.

These final values appear anomalous since the High-Low and Low-Low groups were more efficient than the Low-High group over both the lactational and gestational phases of the cycle when each phase was considered separately, whereas the values calculated for the whole cycle show a disproportionate reduction in the efficiency of the two former groups compared with the latter. The main reason for this anomaly is as follows. Each pound of weight gained by the sow during gestation has been assumed to require 4.925 kcal of metabolisable energy in excess of the energy requirement for maintenance. During lactation, each pound of weight lost has been assumed to yield 3,312 kcal of metabolisable energy. The estimates of efficiency of lactation are confined to the use made of the available energy, and do not take into account the feed energy cost of establishing body reserves.

The estimates of the efficiency of the whole reproductive cycle, however, involve the total feed energy intake during gestation and lactation plus or minus the energy value of any decrease or increase in the weight of the sow at weaning compared with the weight at mating.

For example, the sows of the High-Low group were, on the average, 61 lb heavier at weaning than at mating. This weight increase was part of the 113 lb average weight increment achieved by the animals of this group during gestation, but was not drawn upon to support lactation. The remaining 52 lb of the gestational weight gain, each pound of which required 4,925 kcal, were used during lactation. When drawn upon, each pound only yielded 3,312 kcal. Thus the High-Low group incurred an average energy wastage of approximately 83 therms per sow through building up and subsequently utilising body reserves. The efficiency of the Low-Low group was similarly affected, while the Low-High treatment sows increased in weight over both gestation and lactation, and, therefore, did not incur any catabolic-loss of efficiency.

The values obtained under Method B indicate that the energy return from the investment of feed energy in the sow over the reproductive cycle varies positively but not necessarily proportionately with the amount of feed energy available over and above maintenance requirements. Thus the relatively low efficiency exhibited by the Low-High group over the gestational phase was offset by the higher efficiency exhibited over the lactational phase during which period this group enjoyed a high level of nutrition. The reverse was true of the High-Low group, while the Low-Low treatment sows were penalised by being subjected to a low plane of nutrition throughout the whole reproductive cycle.

The evidence presented above indicates that, in terms of energy return from feed energy invested: (1) the practice of building up sow body reserves during gestation and dissipating these reserves during lactation, is inefficient; (2) that energy recovery increases with increased sow weight gains during both gestation and lactation. The present studies do not indicate the level of feeding or weight increase at which maximum efficiency would be reached and it may be assumed that the law of diminishing returns would operate at a relatively low level in

comparison with that obtaining for fattening pigs, since, in the case of sows, the length of the gestational or lactational period is not shortened as a result of more rapid weight increases, and total maintenance is therefore unaffected.

As has been mentioned in a previous paper, the practical application of an energetically efficient feeding system would result in sows gaining weight during successive gestations and lactations to a point of obesity. It is possible that a sow mated at 230 lb live weight could gain 100 lb in each of her first three gestations, 20 lb in each of the subsequent lactations, and weigh 590 lb at the weaning of her third litter, without any ill effects upon her breeding ability. It is improbable that the process of cumulative weight increases could be continued much beyond this point. In times of national emergency, where energy recovery, including energy in the form of fat, is of importance, a feeding policy which exploited the high energetic efficency of such a system and capitalised on the accumulated energy reserves by slaughtering well-fed and high-condition sows before over-fatness impaired their breeding ability, might well be adopted. In normal times, any decision on the level of feeding to be applied to sows must be taken in relation to the needs and returns from other classes of stock in the herd, and this aspect merits examination in some detail.

It can be assumed that all stock in a herd will be fed sufficient for maintenance. It is, therefore, the disposition of a productive ration which must be considered, and it is on this basis that the following estimates have been prepared. Throughout these studies it has been estimated that a productive ration of 4,925 kcal of metabolisable energy would result in a pound of liveweight gain on a gestating sow. This would provide an increase in tissue energy content of 3.312 kcal.

It was estimated from data presented in an earlier study (Smith 1960) that the feed energy which would produce 780 kcal of tissue energy increase on a sow would produce 1,000 kcal of milk energy. It may therefore be calculated that 4,925 kcal of productive metabolisable energy fed to a lactating sow would result in the production of 4,240 kcal of gross milk energy. This milk energy would produce a tissue energy gain in a litter of 1,933 kcal or 1.7 lb of live weight gain (Table 9).

Further, it may be calculated that a production ration of 4925 kcal would result in a storage of 3312 kcal on a 200 lb bacon pig, or a gain of 1.80 lb liveweight (Woodman 1957).

It would appear, therefore, that: (a) the energy recovery from a given production ration is highest when fed to a gestating sow or a bacon pig and lowest when fed to a lactating sow when, in the latter case, litter growth is considered as the outcome. The data presented in Table 12 support this conclusion in that the High-Low group proved more efficient over the reproductive cycle due to the high efficiency shown over the gestational period. (b) The liveweight gains obtained from a given productive ration are greater for the fattening pig and the litter than for the gestating sow. (c) When the liveweight increment is converted to carcass weight, using the factor 0.8 for the gestating sow and the fattening pig (Smith 1957) and 0.75 for the suckling pig (calculated from the data of Berge and Indrebo 1954), the final outcome is:—

Gestating sow	0.8 lb carcass gain
Suckling litter	1.3 lb carcass gain
200 lb baconer	1.4 lb carcass gain.

Since the price received per pound for a pork or bacon pig in New Zealand is normally double that for a pound of sow meat, the return from a given production ration fed to a bacon pig will be 3.5 times as great as that from the same ration fed to a gestating sow, and the margin for the suckling pig over the sow is only slightly less.

It is realised that the above estimates are subject to quite considerable error, but the margins in favour of the fattening pig and the suckling litter are of such magnitude that it is unlikely that more accurate basic data would lead to any change in the order of the values.

It is also realised that in some cases the composition and the cost of the feeds provided for each of the three classes of stock will modify the margins shown, but again it is unlikely that any reduction in the cost of feeding the gestating sow would completely eliminate the economic advantage of the fattening pig and the litter in terms of returns over feed costs.

In New Zealand, where the total feed available on farms daily throughout the year, is largely determined by, and restricted to, the milk production of the dairy herd, the decision as to how the prescribed feed supply is to be distributed to the various classes of stock is of paramount importance. Under these conditions the feeding policy should aim at:

(1) providing the gestating sow with a ration which will enable her to gain a maximum of 50 lb over the whole gestational period, inclusive of uterine contents;

(2) using bulky cheap feedstuffs, such as grass and roots, to the maximum degree possible during gestation to cheapen further this least remunerative phase of production;

(3) feeding the lactating sow so that she maintains weight; and

(4) diverting all feed in excess of these two basic requirements to commercial fattening stock.

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SELECTION FOR HIGH AND LOW PRODUCTIVITY IN PERENNIAL RYE-GRASS (*Lolium perenne* L.)

I. HERITABILITY STUDY OF EARLY GENERATIONS

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Summary

In *Lolium perenne* the progress of selection for high and low productivity was slow in the second generation, estimates of heritability being generally of the same order (5-30%) as calculated from the preceding generation of diallel crosses of four plants, selected at random from old pastures.

Progress was also influenced by inbreeding depression and some heterosis at different seasons. The effects of selection changed with season, the interaction being most marked in winter.

Selection for tiller number was less efficient than the correlated response in tiller number to selection for herbage production.

Selection for herbage production yielded correlated responses in date of ear emergence, seed-weight, and total seed production.

Introduction

In a previous study (Fejer 1958) the components of variance of herbage yield in a diallel cross of four perennial ryegrass plants selected at random from old pastures were determined, and the prospects of further improvement in New Zealand perennial ryegrass by selection were discussed in relation to tillering habit and inbreeding depression. Variable but generally low heritabilities indicated that progress by selection would be slow in the material used.

It was considered that further fundamental information could be obtained from a study of the problems associated with selection for herbage yield and its component characters in later generations of the same material. A selection programme based on the diallel crosses and their parents was initiated.

Material and Methods

The plants used in the previous experiment (Fejer 1958) were diallel cross progenies selected for difference in herbage yield. One represented a "high"-producing "pasture type" ($B \times C = H_1$) and the other a "low"-producing "hay type" ($A \times D = L_1$), both cross and reciprocals being used.

For the present study three sibs or half-sibs were selected from the 50 plants of each of these progenies. Selection was based on three harvests made between January and April 1953 of non-flowering plants obtained by planting in the previous spring. The plants selected were the high-producing and high-tillering extremes in the "high" line

(HP_1 and HT_1 respectively) and the corresponding low-producing and low-tillering extremes in the "low" line (LP_1 and LT_1 respectively). The second generations of the above selections are designated HP_2, HT_2, LP_2 and LT_2, respectively.

Parents B, C, D, and A were selfed, and selections were then made for high production within B and C selfings (HS_1), and for low production within D and A selfings (LS_1). The second generations from these selected selfings for parents C and D are designated HS_2 and LS_2 respectively.

In addition to the sib-crosses and selfings, comparable non-inbred crosses were made between HS_1 selected selfings of parents B and C (HX_2), and between LS_1 selected selfings of parents D and A (LX_2), together with an out-cross between the high-selection selfings of C and the low-selection selfings of D (HLX_2). A control line derived from the bulking of all diallel crosses of the four parents was also included. The breeding plan is shown in Fig. 1.

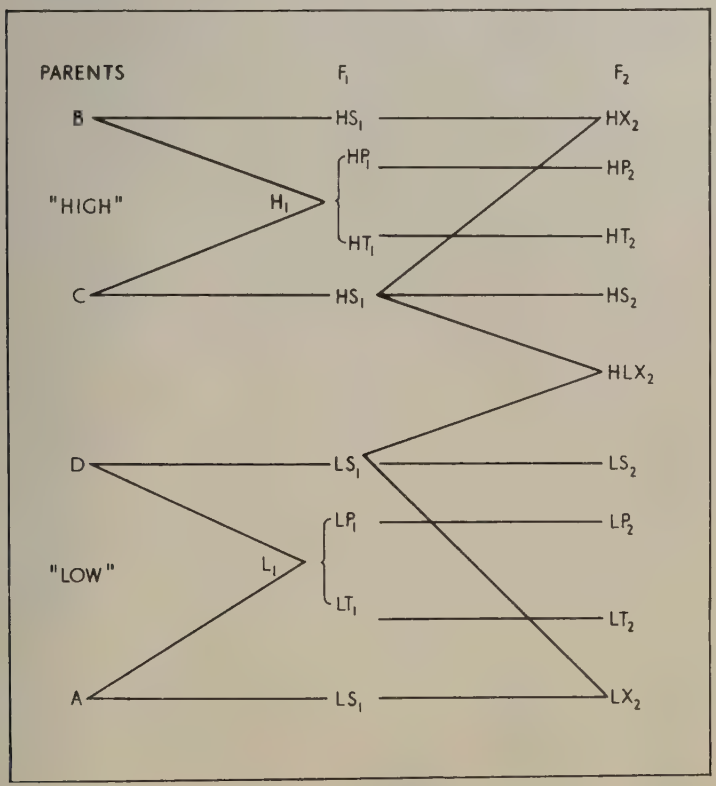

Fig. 1.—Breeding plan.

In the F_1 generation all diallel crosses were made, but only those crosses used to produce F_2s are shown.

The techniques of crossing, planting, and measuring were the same as those used in the previous study.

The F_2 generation was sown in October, and the seedlings planted out in the field in December 1953. These 10 progenies were replicated 27 times in a randomised block design, with one plant per plot.

Greenweight per plant, tiller number per plant, and tiller greenweight per plant, were measured on eight harvest dates between March 1954 and June 1955. In December 1954, the field was closed for open pollination.

For the purpose of this paper, December, January, and February are defined as summer; March, April, and May, as autumn; June, July, and August as winter; and September, October, and November as spring.

Results and Discussion

The mean green weights per plant and coefficients of variation for the eight harvests are shown in Table 1.

The results show strong inbreeding depression, especially in the later weights of the LS_2 progeny.

In the "high" sib-crosses, the yield of the high-tillering progeny (HT_2) was significantly lower than "Control" at all harvests, while the high-production progeny (HP_2) was significantly lower at winter and early spring harvests. With the exception of the March harvest, the mean yields of the "high" out-crosses did not differ significantly from those of the original population (Control). Both "low" sib-crosses had significantly lower yields than "Control" at all harvests, while the "low" out-cross behaved similarly except in March 1954 and February and March 1955.

The wide out-cross (HLX_2) showed quite striking heterosis effects at the last three harvests, but this was associated with relatively high variabilities, and for this reason cannot be explained by "genetic homeostasis" (Lerner 1958). However, genetic homeostasis could explain the inbreeding depression, except at the harvest of February 1955, when there was no inbreeding depression in HS_2, and increased variability.

There was a positive effect of selection at most harvests, although it varied with season and was not significant in the winter. (Winter growth had not been taken into account at selection.) In June 1954, the yields of the "high" and "low" progenies did not differ except in the inbreds, while in June 1955 an apparent reversal in the selection effect for the out-crosses was not statistically significant. A later investigation, carried out in a glasshouse in which environmental factors were controlled, showed this genotype-environment interaction to be a real one, and was explained by cold-resistance. This has already been reported in a short note (Fejer 1955), and will be described in detail in the second paper of this series.

TABLE 1. MEAN GREEN WEIGHTS (W, g/PLANT), AND COEFFICIENTS OF VARIATION (V, %)

		Mar. 54		Apr. 54		June 54		Aug. 54		Sept. 54		Dec. 54		Feb. 55		June 55	
		W	V	W	V	W	V	W	V	W	V	W	V	W	V	W	V
Sib-crosses	HP_2	6.4	66	30.7	39	27.8	41	40.0	50	36.2	48	284	46	33.6	68	15.8	52
	HT_2	5.4	67	27.2	43	23.8	42	34.0	41	29.9	47	192	56	19.2	73	10.1	81
	LP_2	2.7	56	15.5	59	22.0	41	26.5	54	22.6	44	152	50	15.9	85	10.1	93
	LT_2	4.1	97	19.5	76	23.4	73	27.5	84	20.4	72	140	76	15.6	112	9.1	106
Sib-crosses of Selfings	HS_2	1.8	114	13.5	75	14.9	69	23.7	88	19.6	88	154	91	29.3	109	11.8	114
	LS_2	1.3	123	6.6	106	7.8	103	11.3	129	11.6	126	75	143	11.6	190	3.7	164
Out-crosses	HX_2	9.5	58	38.7	42	34.9	30	45.3	37	41.7	37	262	38	31.3	64	14.3	49
	LX_2	6.7	72	27.6	55	30.5	57	40.7	54	30.6	57	223	49	23.0	59	17.2	75
	HLX_2	8.2	60	34.3	48	37.8	38	53.4	52	45.9	39	341	43	58.1	78	29.1	82
Control		7.2	55	33.0	30	37.1	26	56.0	44	45.1	37	302	47	29.4	64	16.7	65
Sig. Diff. at 5% Level		2.0		6.5		6.7		11.5		7.8		58		12.1		6.0	

The above effects influence heritability estimates, and previous calculations of these estimates from the diallel crosses (Fejer 1958, Table 6) showed that they varied with season.

Heritabilities were estimated from the formula (Lerner 1958):

Genetic gain = (Heritability) × (selection differential in actual units).

This was done for each month, by relating second-generation data in any month to the corresponding first-generation data for the nearest month in the preceding year (Fejer 1958, Table 1).

The selection differentials were estimated from the earlier work, by comparing the individual parents with the mean of all diallel crosses (the present "Control" line), but the present data on genetic gain are complicated by the inbreeding depression of the sib-crosses. Heritability estimates were therefore calculated from the following comparisons—

(1) Out-crosses: the 1954 HX_2 and LX_2 with the 1954 Control, and the corresponding 1953 H_1 and L_1 selections with the Control in that year.

(2) Sib-crosses: the gains of HP_2 and LP_2 over their mean value (taken as a stable reference), with the corresponding gains of H_1 and L_1 over their mean in the preceding year.

Examples of both calculations for March 1954 data are shown in Table 2.

All heritability estimates are shown in Table 3.

TABLE 2. Methods of Calculating Heritability

Method	Year	Progeny	Yield (g)	Selection Differential (% of Control)	Heritability
Out-cross	1953	H_1	450	+ 98	
		L_1	96	— 58	
		Control	227		
	1954	HX_2	9.48	+ 32 = h^2 (+ 98)	33
		LX_2	6.67	— 7 = h^2 (—58)	12
		Control	7.19		
Sib-cross	1953	H_1	450		
		L_1	96	± 65	
		Mean	273		
	1954	HP_2	6.44		
		LP_2	2.70	± 41 = h^2 (± 65)	63
		Mean	4.57		

Comparisons between the heritability estimates from the diallel crosses (Fejer 1958) and those in Table 3 are not made because their

TABLE 3. HERITABILITIES (%) OF PLANT WEIGHT AND TILLER NUMBER IN DIFFERENT SEASONS

Character and Selection	Dates of Two Harvests Used in Calculations		Progeny and Direction of Selection		
			Out-cross		
	1954–5	1953	High	Low	Sib-cross
Plant Weight (Weight Selection)	Mar.	Feb.	33	12	63
	Apr.	Apr.	15	26	49
	June	Apr.	— 5	30	18
	Dec.	Jan.	— 13	41	43
	Feb.	Feb.	6	38	55
	June	Apr.	— 13	— 5	32
Tiller Number (Weight Selection)	Mar.	Jan.	74	41	81
	Apr.	Apr.	No Data		68
Tiller Number (Tiller Selection)	Mar.	Jan.	26	39	32
	Apr.	Apr.	No Data		17

standard errors are unknown. However, because most of the heritability estimates of productivity, as calculated by the first method, were in the range 5-30%, it can be stated that the low values calculated from the diallel crosses have been confirmed in the out-crosses of the next generation. It is considered that, by the second method, the differential inbreeding depression produced over-estimates of heritability.

The negative values in June reflect the seasonal interaction in winter, and a similar effect can be observed after flowering in December.

Tiller numbers in the sib-crossed progenies selected for productivity were much higher than could be predicted from the previous heritability estimates (Fejer 1958), but were less in progenies selected for tiller number itself. This is well demonstrated in Table 4, where several correlated effects of selection for herbage weight or for tiller number are shown.

It is clear that, in selecting for tiller number, response to selection for productivity was higher in efficiency than direct selection for tiller number (cf. 121 to 105 in "high" lines and 55 to 70 in "low" lines). This influenced the high "indirect" heritabilities shown in Table 3. Tiller number is strongly influenced by non-genetical factors (Fejer 1958, Table 6), and selection based on this character may result in the selection of low-yielding plants with temporarily high tiller numbers.

Table 4 shows that selection for productivity will result in correlated responses of date of ear emergence and seed weight. In

TABLE 4. Measurements of Some Vegetative and Reproductive Characteristics of Progenies

Progeny		Tiller Number (Mar. 54)	Wght. per Tiller (Mar. 54) (mg)	Date of Ear Emergence (Nov. 54)	Wgt. of Seed per Plant (g)	Wgt. of 100 Seed (mg)	Number of Heads per Plant
Sib-crosses	HP_2	121	57	5.4	20	163	255
	HT_2	105	51	2.4	15	188	196
	LP_2	55	55	0.9	15	231	157
	LT_2	70	64	2.9	9	190	164
Sib-crosses of Selfings	HS_2	78	34	5.8	18	183	260
	LS_2	57	33	2.6	7	200	159
Out-crosses	HX_2	131	71	3.0	21	194	249
	LX_2	80	88	3.5	21	193	202
	HLX_2	110	74	3.4	34	195	329
Control		100	69	2.7	22	211	257
Significant Diff. at 5% Level		17	13	1.1	9	20	59

sib-crosses and selfings there was a significant increase in earliness of ear emergence in the low-producing selections and in lateness of ear emergence in the high-producing selections in several cases, whereas seed-weight was higher in the "low" selections than in the "high" selections. The correlation coefficient for the latter relationship in the sib-crosses was highly significant (—0.435** for 38 d.f.). However, total seed production over all plants was positively correlated with herbage weight (r = 0.631** for 98 d.f.). This was due to the higher number of seed-heads automatically selected in the high-tillering selections, and shows that selection for herbage production resulted in increased seed yields. This agrees with the results obtained by Nielson and Kalton (1959) for *Bromus inermis*.

The general agreement between heritabilities estimated from diallel crosses and those realised after actual selection and recombination shows the importance of additive genetic effects in this material. The practical importance of this in endorsing the present polycross breeding method has been discussed in the earlier publication (Fejer 1958), and similar results have been reported on general combining ability of unselected perennial ryegrass material by Torrie (1957). The necessity of using sufficient plants to minimize inbreeding, as discussed by Corkill (1956), is obvious from the amount of depression caused by sib-crossing in the present material. Although a random sample of unselected breeding material was used in the basic diallel crosses, any generalisations based on the slow progress from selection must be

restricted to similar material. Similarly, no generalisation can be made on heterosis as shown by the one wide out-cross used.

Winter growth in June, and reproductive development in December, were little affected by selection for vegetative characters in the summer. It follows that, owing to genotype-environment interactions, real progress in growth can be expected only in seasons in which the selection takes place.

ACKNOWLEDGMENTS

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STUDIES ON THE EPIZOOTIOLOGY OF *Nematodirus* INFESTATION IN SHEEP IN NEW ZEALAND

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(*Received for publication, 23 August 1960*)

Summary

Epizootiological studies over a three-year period have shown a remarkable regularity in the occurrence and course of *Nematodirus* infestation in lambs. Observations of larval populations on pasture have shown the presence of a small larval peak in the spring followed by a larger peak in the autumn. A trial conducted in the autumn of 1959 has shown the importance of the autumn larval peak with regard to susceptible animals. Differences were found to occur in the duration of spring- and autumn-acquired infestations, and evidence is presented indicating that older sheep do possess some measure of age resistance to *Nematodirus* infestation.

INTRODUCTION

The occurrence and distribution of the three species of *Nematodirus* commonly occurring in sheep in New Zealand is outlined elsewhere (Brunsdon, in press), together with a summary of the symptoms observed by various workers in outbreaks of clinical *Nematodirus* infestation. The object of the present study was to ascertain the epizootiology of *Nematodirus* infestation under New Zealand conditions by following faecal egg counts and pasture larval counts.

MATERIAL AND METHODS

During the years 1956, 1957 and 1958, paddocks on the Department of Agriculture's property at Silverstream, near Wallaceville, were set-stocked with ewes and lambs. Observations each year had revealed a relatively high level of *Nematodirus* infestation in the lambs. In the spring, summer and autumn of 1958–59 a further trial was carried out on ewes and lambs grazing these paddocks, and the course of *Nematodirus* infestation in these animals was followed by means of faecal egg counts and larval counts on pasture.

In the 1958–59 trial the flock consisted of 21 Romney ewes and their 29 lambs. The lambs were born between 28 August and 7 September 1958, and were grazed on the paddocks at the rate of six ewes and nine lambs per acre, from 16 September 1958. The lambs were weaned on 25 November 1958, and on 4 December were drenched with phenothiazine to control *Haemonchus* infestation. On 12 February 1959 the flock was reduced to 17 lambs to allow the addition of extra experimental sheep without exceeding the carrying capacity of the pasture.

As a result of pasture sampling in the two seasons prior to the spring of 1958 it was known that, in addition to the normal spring *Nematodirus* larval peak, another peak regularly occurred in autumn. Previous observations had shown that, when lambs were grazed con-

tinuously on infective pasture, they normally acquired an infestation in the spring. The autumn peak of larvae on the pasture, however, had no apparent effect on the level of infestation in the lambs. To observe the possible effect of this peak on susceptible animals, five worm-free lambs were placed on the pasture with the original lambs on 16 February 1959, immediately prior to the expected autumn larval peak. On the same date a group of five two-tooths which had also been maintained worm-free since birth were also placed on pasture with the original lambs, to ascertain whether any age resistance to *Nematodirus* infestation was exhibited by older susceptible animals. Estimations of the numbers and types of eggs present in the individual samples were made by the modified McMaster method, which will detect the presence of 100 eggs per g of faeces. From the beginning of August 1958 until the end of March 1959 samples of herbage were collected regularly and prepared following

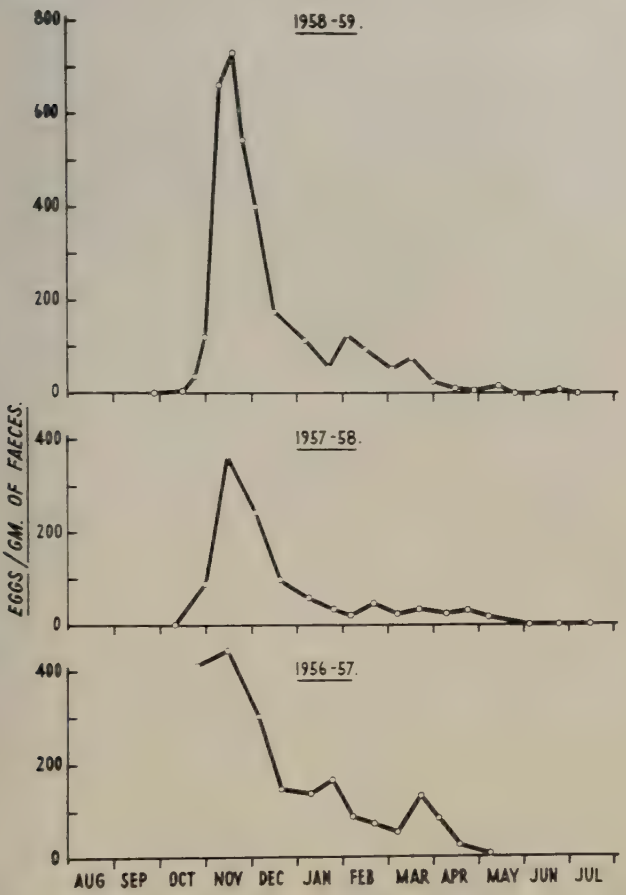

Fig. 1.—Mean *Nematodirus* egg counts of lambs at Silverstream, 1956–59.

Taylor's technique (Taylor 1939) with some minor modifications (Barker unpublished).

RESULTS

Fig. 1 shows the mean *Nematodirus* egg counts of all lambs in the 1958–59 Silverstream trial, and also the egg counts of lambs grazing the same paddocks in the two preceding years.

It will be seen that the pattern and timing of infestation was remarkably regular from season to season. Eggs were first voided in the faeces in the middle of October, the infestation reached a peak in mid-November, then fell rapidly to a relatively low level, at which it continued throughout summer and early autumn. In late autumn the level was further lowered, and the infestation was terminated in early winter, i.e., when the lambs were between 9–10 months of age.

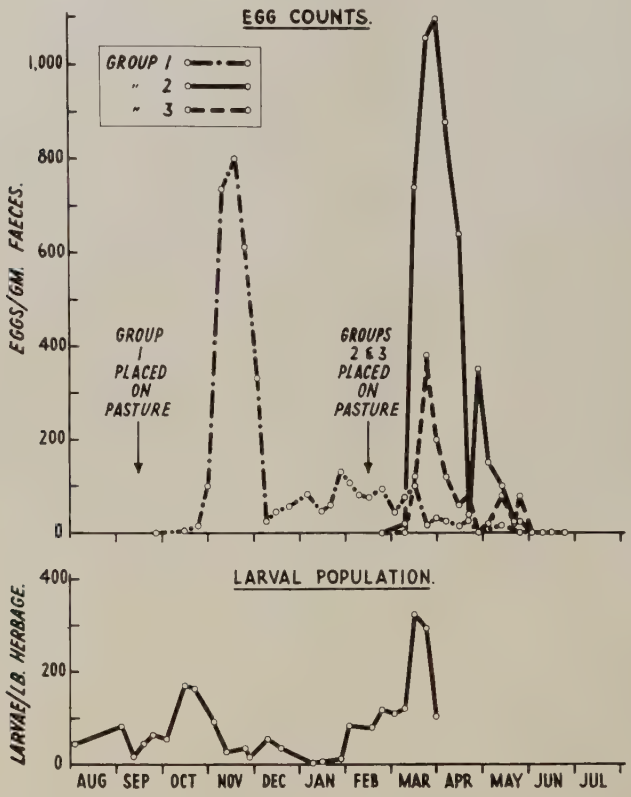

Fig. 2.—Mean *Nematodirus* egg counts of sheep at Silverstream, 1958–59, and larval counts from pasture samples. Group 1—original lambs; group 2—worm-free lambs; group 3—worm-free two-tooths.

Fig. 2 shows the mean *Nematodirus* egg counts of the original lambs, together with those of the worm-free lambs and two-tooths placed on the paddocks in February. Larval counts from pasture samples are also shown. The counts are of larvae recovered and not corrected for losses incurred during the recovery process.

The worm-free lambs placed on the pasture just prior to the autumn larval peak acquired heavier infestations than did the original lambs in the spring. The worm-free two-tooths placed on the pasture on the same date also acquired infestations, but, as indicated by faecal egg counts, these were much lighter than those acquired by the lambs. The autumn-acquired infestations in both the lambs and the two-tooths were terminated at about the same time as those acquired in the spring by the original lambs.

DISCUSSION

In New Zealand, *Nematodirus* spp. are the first strongylid nematodes to be acquired in large numbers by the young lamb, peak infestations occurring before, or at about the time of, weaning. This regular appearance of *Nematodirus* infestation in the spring must depend on the availability of infective larvae on pasture at a time when the herbage intake of the suckling lamb becomes appreciable. In England, Thomas and Stevens (1956) and Spedding *et al.* (1958) found that there was a single larval peak in spring, with larvae present in very low numbers or entirely absent at other times of the year. Baxter (1958), studying *Nematodirus* infestation in Northern Ireland, found the occurrence of two larval peaks on pasture—a large spring peak similar to that described by Thomas and Stevens (1956) and Spedding *et al.* (1958), and an additional smaller autumn peak. Observations at Silverstream during the 1958–59 season and in previous seasons (Barker unpublished) have shown that a small larval peak occurs in September or October, followed by a larger peak in February or March. Tetley (1959), studying the seasonal availability of infective nematode larvae on pasture in the Manawatu District of New Zealand, similarly found, in grazing experiments using lambs raised worm-free, that *Nematodirus* larvae are available in high numbers in the autumn. He concluded that the high incidence of *Nematodirus* in spring lambs is due to the large number of overwintering infective larvae on pasture.

As Baxter (1958) pointed out, the source of the autumn larval peak could be the eggs which had persisted unhatched from the previous season, or eggs deposited in the spring and summer of the current season. He presented evidence indicating that the latter alternative was the more likely. Further support for this view was given by the work of Gibson (1958) on the development and survival of the pre-parasitic stages of *Nematodirus* spp. on pasture. Gibson found that there are considerable differences in the rates of development of the eggs of the various species of *Nematodirus*. He found that the eggs of *N. battus,* which is the predominant species in the majority of infestations in England, deposited on pastures in spring do not reach the infective stage for some four to six months; even then they do not hatch. The majority remain in this stage until the spring following their deposition on the pasture, when they hatch *en masse*. This would result in the single spring larval peak observed by Thomas and Stevens (1956), and Spedding *et al.* (1958).

On the other hand, the eggs of *N. filicollis* behave differently. Gibson (1958, 1959a, b) found that they reach the infective stage more quickly, and eggs voided on the pasture in the spring begin to hatch within about six weeks. As a result, infective larvae are present on the pasture throughout the year, and the tendency to a peak of larval infestation on herbage in the spring is not so pronounced as with *N. battus*. Outbreaks of disease caused by *N. filicollis* alone are, in consequence, not as strictly seasonal as those caused by *N. battus*, and sometimes occur during summer and autumn. Gibson (1958) mentioned observations, as yet unpublished, showing that the eggs of *N. spathiger* develop even more quickly than those of *N. filicollis*. Post-mortem examinations of lambs from Silverstream have shown *Nematodirus* infestation by two species, *N. filicollis* and *N. spathiger*, the former predominating. The findings of Gibson, regarding the rate of development of these species, would thus explain the presence of *Nematodirus* larvae on pasture herbage at Silverstream at all times of the year, with peaks in spring and autumn.

The explanation of the observed larval pattern at Silverstream appears to be as follows: lambs acquire an infestation from the relatively low larval peak on pasture in the spring, and the major proportion of eggs resulting from this infestation commence to develop and begin to hatch in about six weeks, to give the autumn larval peak. Under normal circumstances this autumn larval peak does not affect the immune, spring-infested lambs which continue to void small numbers of eggs throughout the autumn. It seems most likely that the low numbers of eggs voided by the lambs in the autumn, together with a proportion of those passed in summer, survive on the pasture throughout winter, and hatch in the following spring. Thus the spring peak would be composed of larvae hatching from these eggs plus any infective larvae which had survived from the previous autumn.

Faecal egg counts from Silverstream trials show that lambs placed on infective pasture in the spring acquire an infestation which, after reaching a peak in mid-November, rapidly declines to a low level by early December. Following this sudden fall, a fluctuating low egg count is maintained throughout summer and autumn until the infestation is terminated in early winter. The sudden reduction in egg output is best explained as a development of host resistance, but at the present time it is not possible to say whether the reduction is effected by the elimination of worms from the host or by suppression of egg production. The immunity stimulated in the lambs by the spring infestation appears to protect the animals against further infestation at the time of the autumn larval peak. This is probably only true of lambs which continuously graze infective pasture through the summer. Baxter's (1958) studies suggest that previously infested lambs may not have a firm immunity to re-infection when their original infestation is voided or at least non-patent, and when some four months elapse between two encounters with infective larvae.

It might be suggested that the failure of the autumn larval peak to affect the spring-infested lambs was due in part to the fact that the lambs were older and had acquired some measure of age resistance. This possibility was examined by placing susceptible, i.e., worm-free, lambs

on the pasture immediately prior to the autumn larval peak. Faecal egg counts show that these lambs acquired a heavier infestation than did the original lambs in the spring, whilst the egg counts of the latter group showed no response. It is clear from this that age resistance is not a factor in the resistance of spring-infested lambs to the autumn larval peak.

During experiments on the infectivity of pasture, Tetley (1935) found that a sheep exposed to infection for the first time at 10 months of age acquired an infestation. He concluded that the development in the animal of an infestation, at an age when *Nematodirus* had normally disappeared, was indicative that age resistance did not occur. However, results from the present study suggest that older sheep do possess some measure of age resistance. Although worm-free two-tooths did acquire an infestation, it was of a much lower level, as indicated by faecal egg counts, than that acquired by the lambs. In the case of the two-tooths the highest mean egg count was only 380 eggs per g compared with 1,100 eggs per g in the susceptible lambs. However, with the small numbers of animals used, this difference fails to reach significance. It is realised that the total daily faecal output of the two-tooths would exceed that of the lambs, but, because of the greater intake, the number of larvae ingested would also be greater. It follows that, if age resistance did not occur and the two groups were of equal susceptibility, then the larger intake of larvae with its consequent heavier infestation would tend to cancel out the dilution effect upon egg counts of a greater faecal output. Gibson (1959a) demonstrated that sheep over six months of age were resistant to the effects of infestation with *Nematodirus* spp. Although larvae were able to establish themselves in mature sheep, their development was inhibited, and eventually fewer worms reached maturity than in a susceptible eight-weeks-old lamb.

Tetley (1935) found that the duration of *Nematodirus* infection of sheep acquired during the spring and summer period is similar to that of an infection acquired by sheep in the autumn and winter. He concluded therefore that there was no evidence that the external conditions, by modifying the response of the sheep, were effective in causing variations in the course of *Nematodirus* infection from one season to another. It can be seen from Fig. 2 that there was a marked difference in the duration of infestation between the spring-infested lambs and the two autumn-infested groups. In the former group eggs were voided over a period of approximately 222 days, whilst in the latter groups eggs were voided for approximately only 85 days. It must be remembered that egg counts provide only an indication of the duration of infestation. The actual length of the period of an infestation will be greater than that during which eggs are passed on account of the preliminary larval stage and a concluding stage when only non-reproducing adults may be present. The reason for the above discrepancy in duration of infection between the spring- and autumn-infested groups is not known.

The practical application of available knowledge of the epizootiology of *Nematodirus* infestation has been the recommendation of certain grazing procedures (Stamp *et al.* 1955; Thomas and Stevens 1956; Baxter 1958). *Nematodirus* infestation has been recognised as a "lamb

to lamb" disease, each crop of lambs deriving the major portion of its infestation from infection laid down on pasture by the previous year's lambs. As a result, these authors recommend that, during the danger period in the spring when the larval peak occurs, lambs graze only on pasture which did not carry lambs the previous year. Unfortunately, this recommendation is not always easy to apply in practice. However, knowledge of the timing and regularity of appearance of *Nematodirus* infestation in spring makes possible preventive drenching with drugs such as the bephenium compounds. Drenching in the spring, in addition to preventing or controlling current infestation, would also reduce pasture contamination for the following autumn and spring.

Prevention or control of spring infestation is not the only problem. The number of larvae recovered from paddocks which have been grazed by infected lambs in the spring is greatly increased in February and March, resulting in an autumn larval peak of greater magnitude than the spring peak. The results above clearly show that lambs which do not acquire a spring infestation are highly susceptible to the autumn larval peak. The practical importance of this peak is obvious: if lambs which grazed new or non-infective pasture in the spring and summer are transferred in autumn to infective pasture which has been grazed by other lambs in the spring, they can acquire a heavy infestation.

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INSECTS ASSOCIATED WITH THE MAJOR FODDER CROPS IN THE NORTH ISLAND

I. THE GENERAL PICTURE

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(*Received for publication, 16 August 1960*)

Summary

A survey of insects associated with fodder crops in the North Island was carried out during the summer of 1959. The 129 crops studied comprised mainly chou moellier, swedes, turnips, maize, and lucerne. Information on techniques used, location, and condition of crops, and the numbers of insect species associated with the various crops, is given.

Introduction

The purpose of the present survey, which is one of a series aimed at covering the non-forestry agricultural crops, is to provide up to date information on species and their abundance on specific crops.

Fodder crops play an important part in the seasonal production of some 65% of New Zealand dairy farms (N.Z. Dairy Board 1955) and on a great number of sheep farms. They aid in maintaining stock-carrying capacities during winter and summer pasture growth shortages, and assist in preparation of land for pastures. Table 1 shows, by land districts (1956-57), the areas sown and relative importance of the fodder crops sampled in the survey. The major crops studied were lucerne, maize, chou moellier, swedes, and turnips, limited samples of mangels, rape, and pampas also being taken.

In the New Zealand literature some 80 species of insects, of which about 15 are presumed to be beneficial, have been associated with crops—about 60 with crucifers, 15 with lucerne, and 10 with maize. The more important papers are those by Myers (1921), concerning lucerne in the Marlborough seed-growing areas, swedes (Cottier 1932), and cruciferous crops (Todd 1957, 1958, 1959; Lowe 1958). Most of the records, however, concern specific outbreaks rather than attempts at assessing the complex as a whole.

Techniques

The technique used in the collection of samples was similar to that described by Cumber (1958), which involved a sweep-net equipped with detachable end-socks. A sample consisted of 20 sweeps, the net being reversed for successive sweeps of approximately 6ft in progressing forward, and covering in all about 15 sq. yd. In the case of maize, sweeps were taken up the full height of a plant and down another, and sometimes across the tops of plants.

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TABLE 1. Dominion Areas for Major Fodder Crops and Percentage Grown in North Island Districts, 1956–57*

Crop	Dominion Area (acres)	Percentage of Dominion Area					
		Northland	South Auckland	Gisborne	Hawke's Bay	Taranaki	Wellington
Lucerne for hay and silage	137,908	0.6	8.4	0.5	3.5	0.7	2.5
Maize for green feed	4,953	16.3	37.9	6.0	6.1	5.8	19.8
Maize for grain	5,486	4.9	23.0	67.5	4.1	0.07	0.3
Chou moellier	110,722	3.0	11.6	0.4	17.5	4.4	27.9
Soft turnips	166,319	4.3	13.0	0.4	2.9	1.1	5.4
Yellow turnips	57,604	1.4	5.9	0.2	1.6	0.9	4.8
Swedes	179,599	2.1	15.1	0.4	1.5	3.2	5.9
Rape	147,532	0.4	1.0	0.2	4.8	0.1	4.2

* Source: N.Z. Farm Production Statistics.

On removal, the detachable end-sock was closed with a rubber band and placed in a killing jar to which a few drops of ethyl acetate had been added. Samples were transferred to 2-oz holding jars at least one hour, and preferably not longer than four hours, later, since transpiration from crop leaves often present tended to dampen and adversely affect the materials. To facilitate transfers, a wide-mouthed (9 in. diameter) funnel adapted to screw on to holding jars, and a small brush, were used. To assist the further drying out of samples, a hole about $\frac{1}{2}$ in. diameter was drilled in the screw-on lids. This was covered with fine muslin. Pieces of absorbent paper were also added to samples. Insects likely to damage the rest of the sample, e.g.,

Fig. 1

Fig. 2

Fig. 1.—Map showing location of lucerne crop sampling stations.

Fig. 2.—Map showing location of maize crop sampling stations.

soft-bodied caterpillars and *Nezara* adults and nymphs, were discarded after counting at the time of transferring samples to holding jars. Thus the insect materials were kept in good order. On arrival at headquarters 1-2 weeks later they were transferred to petri dishes and held on filter papers, together with a little flake naphthalene.

Soil samples were studied on the spot, and the insect materials were collected and recorded. Most of these samples were six random spade-square samples, including actual plants; they were taken to a depth of about 6 in.

The sampling periods were as follows: East Coast areas, 9.2.59-13.2.59; Northland and Auckland, 23.2.59-5.3.59; West Coast. 16.3.59-20.3.59; Manawatu, 24.3.59; Wellington, 25.3.59; and Wairarapa, 8.4.59. Weather conditions were adequately fine. It was found desirable to delay morning samplings usually till about 9 a.m., by which time the dew had dried off the crops.

Crops were sampled in order of sighting, usually with a minimum distance of 20-30 miles between similar crops, and were numbered consecutively. In all, 129 crops were studied (Table 2), and the distributions of these are shown in Fig. 1 (lucerne), Fig. 2 (maize), Fig. 3 (chou), Fig. 4 (turnips), and Fig. 5 (swedes, mixed chou and swedes). Mangels were sampled at Sanson, Kimbolton, Tiakitahuna, and Ashhurst, rape at Feilding, pampas at Kotemaori, and mixture of rape, swedes and turnips at Feilding and Awahuri-Sanson. At each sampling site details of topography, time of day, weather, soil moisture, height of crop, and weeds present, were recorded. This information is summarised in the Appendix.

Results

This first paper gives only a general picture of the survey. Subsequent papers will discuss details of identity, distribution, and frequency of occurrence, of individual species. The crops considered together yielded in sweep-sampling the following numbers of species: Coleoptera 42, Diptera 50, Hemiptera 50, Hymenoptera 73, Isoptera 1, Lepidoptera 14, Neuroptera 1, Odonata 1, Orthoptera 7, Psocoptera

Fig. 3.—Map showing location of chou moellier crop sampling stations.

TABLE 2. NUMBERS OF SPECIES TAKEN SWEEPING

Crop	No. Crops Studied	Coleoptera	Diptera	Hemiptera	Hymenoptera	Isoptera	Lepidoptera	Neuroptera	Odonata	Orthoptera	Psocoptera	Thysanoptera	Totals
Chou, Swedes mixed	19	11	23	12	23	—	8	1	1	2	1	3	85
Chou	24	10	23	17	32	—	7	1	—	1	—	5	96
Lucerne	15	19	21	18	28	—	8	—	—	3	1	6	104
Maize	34	21	23	28	41	—	9	1	1	4	2	7	137
Mangels	4	2	15	3	9	—	3	—	1	1	2	1	37
Pampas	1	—	—	2	—	—	—	—	—	—	—	—	2
Rape	1	—	6	3	10	—	2	—	—	1	—	1	23
Swedes	8	8	25	7	21	—	3	1	—	—	1	2	68
Turnips	21	17	35	22	38	1	8	1	2	4	2	7	137
Rape, Swedes, Turnips mixed	2	1	2	4	4	—	2	1	—	—	1	—	15

3, and Thysanoptera 11—a total of 253 species. The figures do not differ greatly either in numbers of species or in the relative magnitude of order representation from the data shown in the pasture survey (Cumber 1958). Many of the species taken, as in the pasture survey, have occurred in small numbers only. Many of such species are common to both surveys, and are to be regarded as casual associates.

Table 2 shows the numbers of species in each order taken during the sampling of pure and mixed crops. The figures should be examined in the light of the varying numbers of crops of each category studied.

Discussion

While the limitations set by available facilities are fully realised, nevertheless this survey represents a considerable advance in the understanding of the complex. It is only by seeing repeated occurrences or absences over widespread areas that the full significance of individual species may be gauged. The precise importance of each species, however, must await the results of detailed studies.

The majority of the species encountered were present in small numbers, and many will prove to be only casual associates. However, numerical representation is not necessarily an index of importance.

Fig. 4

Fig. 5

Fig. 4.—Map showing location of turnip crop sampling stations.

Fig. 5.—Map showing location of mixed chou moellier and swedes (black circles), and swede (black triangles), crop sampling stations.

The complex involves an order majority in that group of insects which is largely parasitic, and parasite and host often balance at relatively low populations.

It would seem apparent that surveys such as this will become increasingly affected by the more widespread use of insecticides and that future investigations may possibly show declining insect populations. In the present survey no attempt was made to obtain information on any such treatments which crops had received.

ACKNOWLEDGMENTS

Assistance with field work given by the staff of the Entomology Division sub-station at Palmerston North is gratefully acknowledged; assistance of particular importance was given by Dr R. A. Cumber, who also helped in the planning of the survey and in the presentation of findings.

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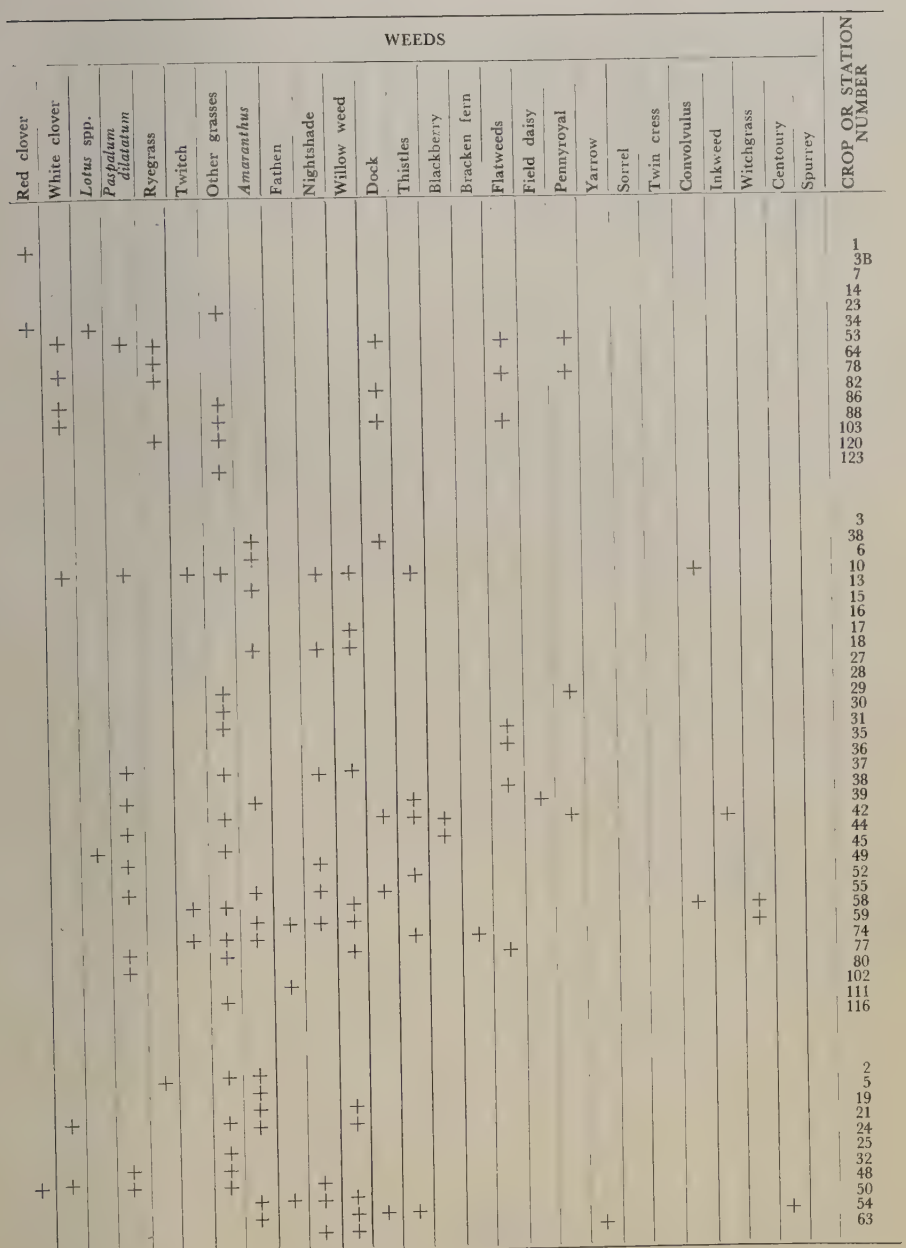
APPENDIX

DETAILS OF SAMPLING STATIONS

CROP OR STATION NUMBER	LOCATION	DATE (1959)	TIME Nearest daylight hour	WEATHER A, Sunny; B, Cloudy; C, Strong Wind	TOPOGRAPHY F, Flat; H, Hilly; R, Rolling	SOIL MOISTURE D, Dry; M, Moist; W, Wet	GRAZING C, Cattle; H, Horses; S, Sheep	Height of Crop
Lucerne								(in.)
1	Takapua plains	9.2	10	A	F	D		18
4	Waipawa, Argyle Road	9.2	12	A	F	D		6–12
7	Greenmeadows	9.2	2	A	F	D		18
14	Gisborne, 6M. South	10.2	2	B	F	M		18–24
23	Waiotapu	12.2	4	B	F	M		6–12
34	Kapiro (Waipapa)	24.2	11	A	F	M		12–18
53	Cambridge	3.3	1	A	F	M		15
64	Bulls, 4M. West	16.3	10	B	R	M		12–15
78	Te Awamutu, 5M. West	19.3	12	A	F	M		18
82	Otorohanga, 2M. West	19.3	6	B	H	M		12
86	Taumarunui, East	20.3	11	B	R	M		18
88	Ohingaiti, 1M. South	20.3	4	B	R	M		12–15
103	Longburn	24.3	4	A	R	D		15
120	Martinborough, 7M. South	8.4	12	A	F	D	C	3–4
123	Greytown	8.4	2	A	F	M	S	6–8
Maize								(ft)
3	Waipawa, 2M. North	9.2	11	A	F	D		9
3B	Waipawa, 2M. North	9.2	11	A	F	D		2½
6	Taradale, 3M. South	9.2	2	A	F	D		10
10	Wairoa, 1M. North	10.2	10	V	F	M		9
13	Hangaroa	10.2	2	V	R	M		9
15	Tolaga Bay	10.2	4	BC	F	M		7
16	Te Kaha, 2M. North	11.2	6	A	F	M		2½
17	Torere	12.2	10	A	F	M		4
18	Whakatane	12.2	11	A	F	D		8
27	Kaitaia, 4M. North	23.2	3	AC	F	M		5
28	Kaitaia, 4M. North	23.2	3	AC	F	M		8
29	Kaitaia, 6M. South	23.2	3	AC	F	W		6–8
30	Mangamuka	23.2	5	B	F	M		5–7
31	Pakaraka, 5M. South	24.2	9	A	R	M		9
35	Ngawha	25.2	9	B	F	M		7–9
36	Taheke	25.2	11	B	F	M		6–8
37	Whirinaki	25.2	12	A	F	D		8
38	Dargaville, 6M. North	25.2	5	A	F	M		3–8
39	Dargaville, 5M. South	26.2	10	A	F	D		2–7
42	Whangarei, 3M. South	26.2	3	B	H	D		4
44	Awarua	26.2	6	B	F	M		6–9
45	Kamo	2.3	12	A	F	D		9
49	Helensville	2.3	5	A	F	M		9
52	Ohinewai	3.3	12	A	F	D		9
55	Eureka	3.3	3	A	F	M		10
58	Tauranga	4.3	11	A	F	M		6–8
59	Papamoa	4.3	12	A	R	D		7
74	Pio Pio	16.3	6	A	H	D		4–6
77	Rukuhia	19.3	12	A	F	D		10
80	Te Kawa	19.3	2	A	R	M		6
102	Longburn	24.3	4	A	F	M		10
111	Shannon, 3M. North	25.3	4	A	F	W		5
116	Dannevirke	26.3	11	B	F	M	C	5
Chou moellier								(ft)
2	Waipukurau	9.2	10	A	R	D		2
5	Waipawa, 5M. North	9.2	12	A	R	D		3–4½
19	Whakatane, 4M. South	12.2	2	A	F	M		3–4
21	Rotorua	12.2	3	A	F	M		4
24	Bay View	13.2	1	A	F	D	S	½–1
25	Puketona	23.2	9	B	H	W		1
32	Pakaraka	24.2	10	A	R	D	S	3–4
48	Waitoki	2.3	4	A	R	D		2
50	Mercer	3.3	11	A	F	D	S	3
54	Cambridge	3.3	2	A	R	M		3
63	Bulls, 3M. West	16.3	9	A	R	W		2


WEEDS
Red clover
White clover
Lotus spp.
Paspalum dilatatum
Ryegrass
Twitch
Other grasses
Amaranthus
Fathen
Nightshade
Willow weed
Dock
Thistles
Blackberry
Bracken fern
Flatweeds
Field daisy
Pennyroyal
Yarrow
Sorrel
Twin cress
Convolvulus
Inkweed
Witchgrass
Centoury
Spurrey
CROP OR STATION NUMBER
1
3B
7
14
23
34
53
64
78
82
86
88
103
120
123
3
38
6
10
13
15
16
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63

CROP OR STATION NUMBER	LOCATION	DATE (1959)	TIME Nearest daylight hour	WEATHER A, Sunny; B, Cloudy; C, Strong Wind	TOPOGRAPHY F, Flat; H, Hilly; R, Rolling	SOIL MOISTURE D, Dry; M, Moist; W, Wet	GRAZING C, Cattle; H, Horses; S, Sheep	Height of Crop
	Chou moellier—Cont.							(ft)
70	Urenui	16.3	3	A	F	M		4
76	Rukuhia	19.3	11	A	F	M		5
78	Kihikihi	19.3	2	A	F	M		5
85	Taumarunui, 6M. North	20.3	10	B	R	M		1
90	Palmerston North, 1M. West	24.3	9	A	F	M		6
93	Marton, 2M. South	24.3	10	A	R	M		2½
100	Cheltenham	24.3	3	A	F	D		4
106	Manakau, 7M. South	25.3	11	B	R	M		2
108	Pahautanui	25.3	2	A	F	M		2½
114	Ashhurst, 1M. South	26.3	10	B	F	D		1
117	Dannevirke	26.3	11	B	F	M		4
121	Greytown, 5M. South	8.4	1	A	F	W		1
124	Carterton, 4M. North	8.4	2	A	F	M		4
	Chou moellier plus swedes							(ft)
8	Kotemaori, 3M. South	9.2	5	A	H	D		
40	Maungaturoto	26.2	12	B	H	D		½
57	Waihi, 3M. South	3.3	5	A	H	M		1½
61	Wharepaina	4.3	3	A	F	M		2
62	Irirangi	5.3	11	AC	H	M	S	½–1
65	Wanganui	16.3	10	B	F	M		3
68	Inglewood	16.3	2	B	H	M		1½
71	Mokau	16.3	4	A	R	D		1
72	Mahoenui, 2M. South	16.3	5	A	H	M	S	1
75	Pio Pio, 4M. North	16.3	6	A	R	M		4
81	Te Raumoa, 2M. West	19.3	5	A	H	M		1½
83	Otorohanga, 2M. West	19.3	6	A	H	M		2
89	Ohingaiti, 1M. South	20.3	4	B	F	M		4½
98	Kimbolton	24.3	2	A	R	M		2
105	Foxton, 3M. North	25.3	10	A	F	W		4
110	Levin	25.3	4	A	F	M		4
118	Pirinoa	8.4	12	A	F	M		2
125	Masterton	8.4	3	A	F	D		1½
127	Konini, 5M. South	8.4	4	A	F	M		1½
	Turnips							(in.)
11	Marumaru	9.2	10	B	H	M	S	—
12	Tiniroto	9.2	12	B	F	M		8
20	Te Teko	12.2	2	A	R	M		10
26	Oruaiti	23.2	12	A	R	M		6
33	Puketona	24.2	10	A	H	M		4
41	Maungaturoto	26.2	12	B	H	D		12
43	Parakao	26.2	4	B	R	D		3
47	Silverdale	2.3	3	A	H	D		8
51	Rangiriri	3.3	11	A	F	D	S	—
56	Waitoa	3.3	4	A	F	M		12
60	Te Puke	4.3	12	A	F	M		12
73	Mohoenui	16.3	5	A	H	M		12
84	Te Kuiti	20.3	9	B	H	M		10
87	Ohingaiti	20.3	4	B	F	M		12
95	Marton, 4M. East	24.3	12	A	F	M		12
101	Te Arakura	24.3	3	A	F	M	S	—
107	Pukerua Bay	25.3	12	A	H	D		8
109	Otaki	25.3	3	A	F	D		10
112	Makerua	25.3	5	A	H	D		10
122	Greytown	8.4	1	A	F	M		12
126	Masterton, 5M. North	8.4	3	A	F	D		12
	Swedes							(ft)
22	Waimangu	12.2	4	B	F	M		1½
66	Eltham	16.3	1	A	F	M		1½
67	Ngaere	16.3	2	A	R	M		2
69	Waitara	16.3	3	B	F	M		2
94	Marton, 4M. East	24.3	11	A	F	M		1½
113	Makerua	25.3	5	A	H	D		1½
119	Pirinoa	8.4	12	A	R	D		1½
128	Pahiatua	8.4	4	A	R	W		1½

WEEDS

Red clover	White clover	*Lotus* spp.	*Paspalum dilatatum*	Ryegrass	Twitch	Other grasses	*Amaranthus*	Fathen	Nightshade	Willow weed	Dock	Thistles	Blackberry	Bracken fern	Flatweeds	Field daisy	Pennyroyal	Yarrow	Sorrel	Twin cress	Convolvulus	Inkweed	Witchgrass	Centaury	Spurrey	CROP OR STATION NUMBER
																										70
																										76
																										78
																										85
																										90
																										93
																										100
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																										119
																										128

CROP OR STATION NUMBER	LOCATION	DATE (1959)	TIME Nearest daylight hour	WEATHER A, Sunny; B, Cloudy; C, Strong Wind	TOPOGRAPHY F, Flat; H, Hilly; R, Rolling	SOIL MOISTURE D, Dry; M, Moist; W, Wet	GRAZING C, Cattle; H, Horses; S, Sheep	Height of Crop
	Mangels							(ft)
92	Sanson	24.3	9	A	F	D		1⅓
99	Kimbolton	24.3	2	A	F	D		1½
104	Tiakitahuna	25.3	9	A	F	M		1⅓
115	Ashhurst bridge	26.3	11	B	F	M		1½
	Rape							(ft)
97	Feilding, 4M. West	24.3	12	A	H	D		2
	Pampas							(ft)
9	Kotemaori	9.2	5	A	H	M		5
	Rape, Swedes, Turnips, mixed							(ft)
91	Awahuri-Sanson	24.3	9	A	F	M		2
96	Feilding, 5M. West	24.3	12	A	R	M		2

WEEDS																									CROP OR STATION NUMBER
Red clover	White clover	*Lotus* spp.	*Paspalum dilatatum*	Ryegrass	Twitch	Other grasses	*Amaranthus*	Fathen	Nightshade	Willow weed	Dock	Thistles	Blackberry	Bracken fern	Flatweeds	Field daisy	Pennyroyal	Yarrow	Sorrel	Twin cress	Convolvulus	Inkweed	Witchgrass	Centoury	Spurrey	
+																										92
				+				+	+	+	+							+		+					99
						++			+++	++	++	++														104
																										115
								+	+	+	+	+														97
						+																				9
				+					+	+																91
																										96

THE EFFECT OF INTAKE OF SUPPLEMENTARY FOOD BY THE SUCKLING LITTER UPON WEIGHT GAINS AND UPON THE ENERGETIC EFFICIENCY OF THE REPRODUCTIVE CYCLE

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(*Received for publication, 12 May 1960*)

Summary

Two experiments are described. The first was conducted in the summer with 10 first-litter sows, five of whose litters were offered creep feed from the age of three weeks. In the second experiment, conducted in the spring, 11 second-litter sows were used, five of whose litters were offered creep feed.

The average milk and milk energy yields of the four treatment groups were: summer experiment—creep-fed group, 621 lb and 374 therms*; no-creep, 639 lb and 379 therms; spring experiment—creep-fed, 772 lb and 493 therms; no-creep, 813 lb and 514 therms.

In both experiments the sows whose litters did not receive creep produced more milk over the last four weeks of lactation than the sows whose litters received creep feed. The sows in the no-creep groups lost more weight over lactation.

The creep-fed pigs were on the average 11 lb heavier at weaning than those not receiving creep.

The gross efficiency of milk production of the sows was not affected by treatment of the litters.

It was estimated from the combined data from the two experiments that five therms of sow feed intake were required to produce one pound of weight gain on the litter over the last four weeks of lactation, while only 2.4 therms of litter intake from the creep produced the same weight increase. As a result, the creep-fed groups exhibited a higher efficiency of feed conversion than the no-creep groups.

Introduction

The provision of supplementary feed for suckling pigs in an area of the pen called a "creep", to which the litter, but not the sow, has access, has been a recommended practice for many years.

There is ample evidence, based mainly upon observation, that creep feeding results in heavier weaning weights than are obtained when the litter is entirely dependent upon the sow for its food. The precise value of the practice, in terms of greater litter growth, cannot be determined, however, except under strictly controlled experimental conditions which include the measurement of the yield and composition of the milk of the dams of litters receiving creep feed compared with similar measurements for litters not receiving creep feed.

In previous studies of sow milk production carried out at this station, the effect of creep intake upon the energetic efficiency of litter production was estimated (Smith 1959a, b). These estimates are valid, however, only if it is assumed that there is no interaction between milk yield and creep intake.

* One therm = 1,000 kilocalories.

The experiments reported here were conducted to determine:

(1) the magnitude of the extra weight gains that could be obtained through creep feeding;

(2) the effect of the presence or absence of supplementary feed upon the amount of milk withdrawn from the sow by the litter;

(3) the effect of supplementary feeding upon the energetic efficiency of litter production.

EXPERIMENTAL METHODS AND MATERIALS

Two experiments were conducted. The first was carried out in the summer and involved 10 Large White × Berkshire first-litter sows. Five of the litters from these sows received supplementary feed from the end of the third week until weaning at eight weeks, while five received no feed other than their dams' milk. The second experiment was carried out in the spring, with second-litter sows of similar breeding to those used in

TABLE 1. LITTER NUMBERS, THE NUMBER OF PIGS SUCKLED BY THE SOWS IN THE TWO EXPERIMENTS AND THE LITTER GAINS BETWEEN BIRTH AND THREE WEEKS OF AGE

Creep				*No Creep*			
Sow No.	Litter No.	No. Of Pigs	Wt. Gain Birth To 3 Weeks (lb)	Sow No.	Litter No.	No. Of Pigs	Wt. Gain Birth To 3 Weeks (lb)
			Summer Experiment				
135	1	8	39.3	140	1	8	63.6
136	1	8	58.2	141	1	8	60.9
137	1	8	70.4	142	1	8	79.5
138	1	8	52.1	143	1	8	80.7
139	1	7	77.4	144	1	7	41.9
Total		39	297.4			39	326.6
Mean per litter		7.8	59.5			7.8	65.3
or per pig			7.6				8.4
			Spring Experiment				
145	2	12	82.5	150	2	11	71.9
146	2	10	85.2	151	2	11	91.8
147	2	9	86.5	152	2	10	81.7
148	2	8	65.3	153	2	8	65.7
149	2	8	74.7	154	2	8	73.2
				155	2	8	68.9
Total		47	394.2			56	453.2
Mean per litter		9.4	78.8			9.3	75.5
or per pig			8.4				8.1

the first experiment. Five litters received supplementary feed, while the remaining six did not. This latter trial was started with 12 sows, but one failed to milk and her litter was removed for hand rearing.

The sows were allocated to treatments when litters reached three weeks of age, groups being balanced as closely as possible for numbers of piglets and weight gains from birth.

The final allocations are shown in Table 1.

As can be seen, the attempt to equalise the weight gains of the litters was not entirely successful.

In the first experiment the "no-creep" litters made slightly greater gains up to three weeks, while the reverse was true in the second experiment.

In the summer trial the sows were fed a ration consisting of 60% separated milk and 40% concentrate on a feed unit basis, at the daily rate of four units per sow and one unit per piglet suckled. (One gallon of milk or one pound of concentrate was regarded as a feed unit.) The sows in the spring experiments were fed entirely upon separated milk at the daily rate of four units per sow and two-thirds unit per piglet suckled.

The creep feed consisted of concentrates (one part meat meal to three parts barley meal by weight) and separated milk in separate troughs fed to appetite. Creep consumption was measured on a weekly basis.

The management and housing of the sows and litters, the technique used in measuring the sow milk yield, and the methods employed in calculating the energetic efficiency of gestation and lactation were as described in previous papers (Smith 1959a, 1960a), except in one particular: in the present experiment sow milk analyses were confined to the determination of the fat and total solids content. Previously determined average values for lactose and ash were used and the protein content obtained by difference (Perrin 1954).

Results

The yield and composition of the milk produced by the sows in the two experiments, together with the milk energy yields, are shown in Table 2.

The effects of stage of lactation and treatment upon the yield and composition of the milk are shown in Fig. 1.

It is apparent that the feeding treatment to which the litters were subjected had no real influence upon the composition of their dams' milk, but there was a tendency for the older sows in the spring experiment, whose litters did not receive supplementary feed, to produce more milk through achieving a higher peak production and maintaining a higher yield over the last three weeks of lactation.

The no-creep group in the summer experiment also reached a higher peak and persisted at a higher level of production over the last three weeks than the creep-fed group, but this increase was partly offset by a lower yield over the first three weeks of lactation. This distribution of

TABLE 2. MILK YIELDS AND COMPOSITION AND THE MILK ENERGY YIELDS OF THE SOWS IN THE TWO EXPERIMENTS

Sow No.	Milk Yield (lb)	Fat (%)	Prot. (%)	Lact. (%)	Milk Energy *(Therms)
		Summer Experiment			
Creep					
135	459	7.4	6.2	4.6	254
136	626	8.7	6.3	4.6	383
137	664	9.1	6.0	4.6	412
138	632	8.4	6.7	4.6	381
139	722	8.3	6.7	4.6	438
Per sow	622.5	8.4	6.4	4.6	373.5
Per piglet	80.0				47.9
No Creep					
140	646	8.7	6.4	4.6	396
141	693	8.1	6.8	4.6	402
142	701	8.4	6.5	4.6	420
143	706	8.0	6.3	4.6	426
144	447	7.5	6.5	4.6	253
Per sow	638.6	8.1	6.5	4.6	379.2
Per piglet	80.8				48.6
		Spring Experiment			
Creep					
145	756	9.2	6.1	4.6	474
146	855	9.2	6.1	4.6	536
147	796	10.0	6.1	4.6	524
148	730	10.3	5.6	4.6	480
149	723	9.1	6.2	4.6	449
Per sow	772	9.6	6.0	4.6	492.6
Per piglet	82.1				52.4
No Creep					
150	814	8.8	6.1	4.6	496
151	957	9.7	6.3	4.6	622
152	886	8.9	6.1	4.6	541
153	737	10.1	5.8	4.6	481
154	772	9.6	5.9	4.6	491
155	709	9.7	5.9	4.6	454
Per sow	812.5	9.5	6.0	4.6	514.1
Per piglet	87.1				55.1

* One therm = 1,000 kilocalories.

production would suggest that the litters which received no supplementary feed after reaching three weeks of age drew more heavily upon their dams than those which had the opportunity of satisfying part of their food requirements from the creep.

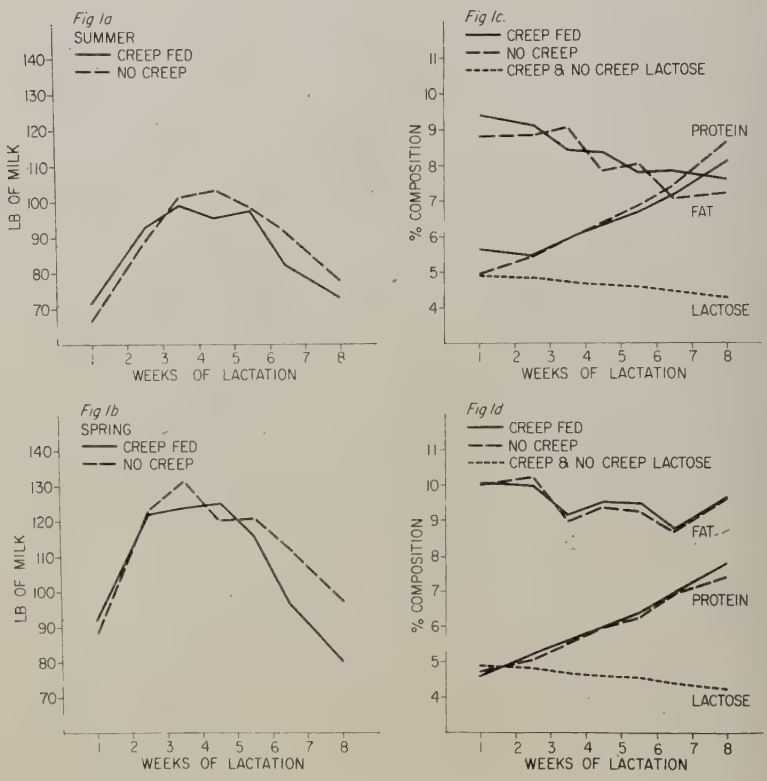

Fig. 1.—The effect of stage of lactation upon the yield and composition of the milk.

The Gross Efficiency of Milk Production

The gross efficiencies of milk production are shown in Table 3.

The data in Table 3 indicate that the increase in milk energy yield which occurred among the sows whose litters received no creep was supported by an increased use of body reserves, and the gross efficiency of milk production was not affected. A further point of interest is the difference in efficiency values in the two experiments. The fact that only maiden sows were used in the first experiment conducted in the summer, while only second-litter sows were used in the spring experiment, may reduce the validity of any comparisons, although there has been no evidence from previous studies that the age of the sow has influenced the efficiency of milk production. On the other hand, there has been evidence presented (Smith 1959a) in line with the present findings that the gross efficiency of milk production in the spring was higher than in the summer.

TABLE 3. GROSS EFFICIENCY OF MILK PRODUCTION OF THE INDIVIDUAL SOWS IN THE FOUR GROUPS (ENERGY VALUES IN THERMS)

Sow No.	Sow Feed Energy Intake	Sow Wt. Change (lb)	Energy Equiv. Of Wt. Change	Equiv. Energy Intake	Milk Energy Yield	Gross Efficiency Milk Prod. (%)
			Summer Experiment			
Creep						
135	809	+11	— 56	753	254	33.7
136	809	—31	+102	911	383	42.0
137	794	—37	+123	917	412	44.9
138	809	—18	+ 56	865	381	44.0
139	743	—33	+110	853	438	51.4
Means	792.8	—21.6	+ 67.0	859.8	373.6	43.4*
No Creep						
140	803	—26	+ 86	889	396	44.5
141	804	— 6	+ 14	818	402	49.1
142	809	—37	+121	930	420	45.2
143	809	—37	+117	926	426	46.0
144	605	—56	+176	781	253	32.4
Means	766.0	—32.4	+102.8	868.8	379.4	43.7
			Spring Experiment			
Creep						
145	805	—41	+136	941	474	50.4
146	707	—37	+118	825	536	65.0
147	677	—68	+225	902	524	58.1
148	636	—41	+136	772	480	62.2
149	636	—52	+172	808	449	55.6
Means	692.2	—47.8	+157.4	849.6	492.6	58.0
No Creep						
150	766	—51	+169	935	496	53.1
151	771	—62	+205	976	622	63.7
152	707	—68	+226	933	541	58.0
153	633	—67	+222	855	481	56.3
154	636	—64	+212	848	491	57.9
155	636	—50	+166	802	454	56.6
Means	691.5	—60.3	+200.0	891.5	514.1	57.7

* Weighted means.

The Effect of Creep Feeding upon Litter Gains and Efficiency

The feed energy intake of the litters of the sows in the four groups, together with their weight gains and the energy requirements per pound of gain, are shown in Table 4.

The piglets receiving creep feed were on the average 11 lb heavier at eight weeks of age than those not receiving creep.

TABLE 4. Weight Gains and Energy Requirement per Pound Gain of the Creep-Fed and Non-Creep-Fed Litters

Treatment	Summer		Spring	
	Creep	No Creep	Creep	No Creep
Mean wt. gain per pig 0-3 weeks inclusive	7.6	8.4	8.4	8.1
Mean wt. gain 4-8 weeks inclusive	24.7	13.8	25.4	14.4
Energy intake 4-8 weeks in therms from:				
Sow's milk	32.6	34.0	35.3	37.7
Creep	28.6	——	27.1	——
Total	61.2	34.0	62.4	37.7
Therms intake per lb gain	2.48	2.46	2.46	2.62

The energy requirement per pound of gain was similar for the creep and no-creep litters in the summer experiment, but in the spring trial the piglets receiving no supplements were slightly less efficient than the creep-fed group. This difference in the mean requirement per pound of gain was, however, largely due to the influence of one litter whose intake was 2.9 therms per pound of gain.

The Effect of Creep Feeding upon Feed Conversion Efficiency during Lactation

Figs. 2, 3, and 4 show, on a weekly basis, the level of efficiency achieved in milk production and feed conversion by the sows and litters over the seven weeks of recorded lactation.

Over the last four weeks of lactation the combined energy conversion efficiency of the sows and litters of the creep-fed groups was substantially higher than that of the groups not receiving creep feed (Figs. 2a and b). This fact is further illustrated in Table 5. (The data shown are the intake equivalent of the sow and the creep intake of the litter.) It is also evident from Figs. 3a and b that this increased efficiency in the last four weeks was not due to consistently better feed conversion by the creep-fed litters; nor, as is evident from Figs. 4a and b and Table 3, was it due to a greater efficiency of milk production by the dams of the creep-fed groups.

The differences shown in Figs. 2a and b may be explained on the basis of the data shown in Table 6.

Fig. 2.—The mean feed energy intake equivalent of sows and litters per pound of litter gain.

Fig. 3.—The mean feed energy intake of the litters from sows' milk and creep feed per pound of litter gain.

Fig. 4.—The mean feed energy intake equivalent of the sows per therm of milk energy produced.

Fig 2a

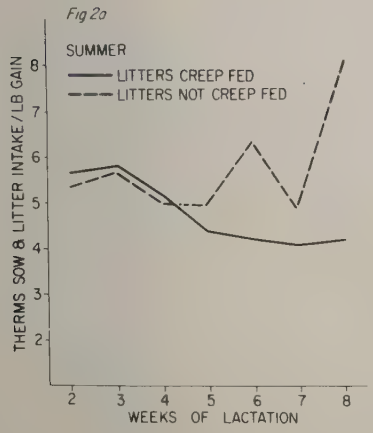

Fig 2b

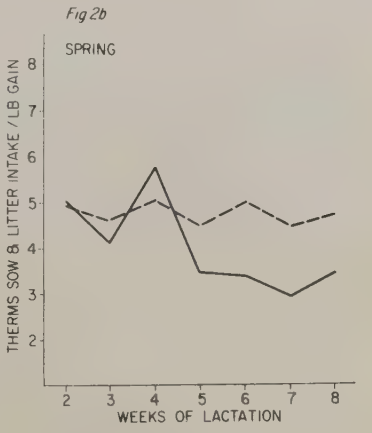

Fig 3a

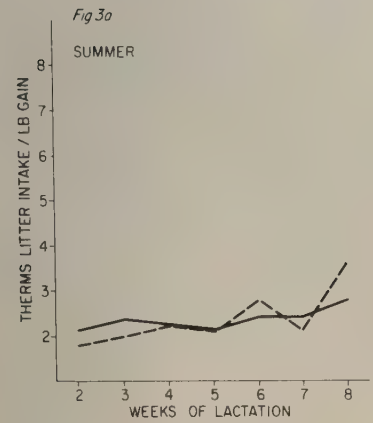

Fig 3b.

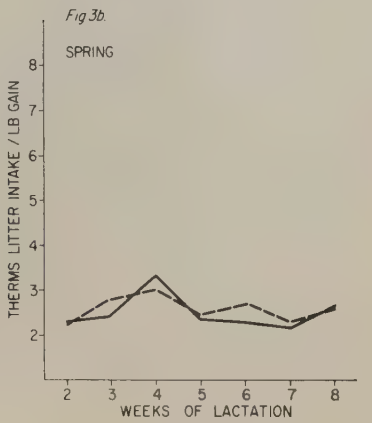

Fig 4a

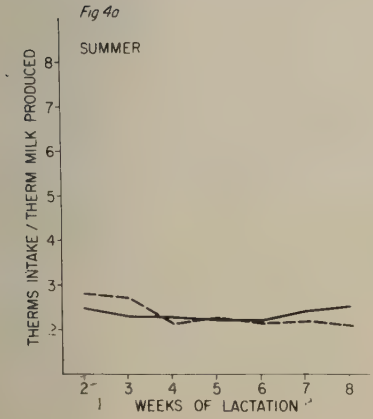

Fig 4b.

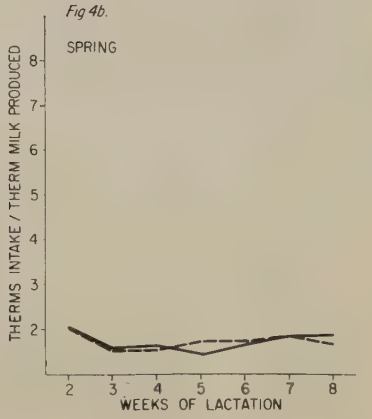

TABLE 5. MEAN ENERGY INTAKE PER SOW AND LITTER PER POUND OF LITTER GAIN OVER THE FIRST THREE AND LAST FOUR WEEKS OF LACTATION (ENERGY VALUES IN THERMS)

Treatment	Summer		Spring	
	Creep	No Creep	Creep	No Creep
Therms feed energy per lb gain for:				
2–4 weeks, incl.	5.5	5.4	4.9	4.8
5–8 weeks, incl.	4.2	5.8	3.3	4.6
for whole period	4.6	5.6	3.7	4.7

TABLE 6. SOW-FEED ENERGY INTAKE EQUIVALENT COMPARED WITH THE CREEP-FEED ENERGY INTAKE PER POUND OF LITTER GAIN (ENERGY VALUES IN THERMS)

Treatment	Summer		Spring	
	Creep	No Creep	Creep	No Creep
No. of sows	5	5	5	6
Sow feed energy intake equiv. last 4 weeks of lact.	2,388	2,364	2,329	3,066
Creep feed energy intake, last 4 wks.	1,090	——	1,269	——
Energy content of sow's milk	993	1,035	1,298	1,657
Litter gains (lb)	834	410	1,087	660
Sow milk and creep feed energy per lb litter gain	2.5	2.6	2.4	2.5
Litter weight gain due to sow's milk (lb)	397	410	550	660
Litter wt. gain due to creep intake (lb)	437	——	537	——
Sow feed energy per lb litter gain from sow milk	6.0	5.8	4.2	4.6
Sow and creep feed energy per lb litter gain	4.2	5.8	3.3	4.6

As shown in Table 6, 2,388 therms of sow-feed energy equivalent were processed by the sows in the summer creep-fed group to produce 993 therms of metabolisable milk energy. This milk was in turn processed by the litters to produce an estimated weight gain of 397 lb—an intake of six therms per pound of liveweight increase.

In comparison 1,090 therms of feed energy consumed by the piglets directly from the creep produced a gain of 437 lb—an efficiency of 2.5 therms per pound of weight increase.

The increased efficiency of the creep-fed groups over the last four weeks of lactation, both as compared with the efficiency of the no-creep

groups in the same period, and with their own efficiency in the first three weeks, was, therefore, largely due to the fact that 31% of the combined feed energy intakes of the sows and litters in the summer experiment and 35% in the spring were derived by the piglets directly from the creep, while in the case of the no-creep groups for the whole lactation, and the creep-fed groups for the first three weeks, all the feed consumed by the litters was first processed by the sow.

The Energetic Efficiencies of Gestation, Lactation, and the Whole Reproductive Cycle

The two methods used in calculating the energetic efficiencies shown in Table 7 have been described previously (Smith 1960a), but an indication of the meaning of the values is appropriate here.

Under Method A the values obtained are the calories recovered as litter energy at birth or weaning for each 100 calories of sow and litter feed energy intake equivalent. (The energy contents of sow weight losses or gains during the period under consideration have been related to sow intake.)

Under Method B the values obtained are the recovery in the form of sow and litter tissue energy per 100 calories of observed sow and litter feed energy intake.

Unfortunately the gestation intakes of the sows used on the summer experiment were not recorded. The gestation intakes of the spring groups include an estimated energy intake from pasture (Smith 1960a).

TABLE 7. COMPARISON OF ENERGETIC EFFICIENCIES

Treatment	Method A				Method B			
	Summer		Spring		Summer		Spring	
	Creep	No Creep	Creep	No Creep	Creep	No Creep	Creep	No Creep
	%	%	%	%	%	%	%	%
Gestation			1.78	1.74			27.8	26.9
Lactation	23.7	20.5	29.3	23.8	19.3	10.9	17.0	0.40
Reproductive Cycle			18.8	13.9			22.7	15.4

The values shown in Table 7 are of the same order as those obtained in previous studies (Smith 1960a, b). The essential features in terms of the present investigation are as follows.

Under Method A: (i) During lactation an additional 3.2% and 5.5% of the energy intake equivalent of the sows and litters were recovered as litter energy when creep was fed during the summer and spring experiments respectively. (ii) Over the whole reproductive cycle the recovery in the form of litter energy was 4.9% higher in the creep-fed group.

Under Method B, the total recovery in the form of sow and litter energy during lactation was 8.4% greater for the creep-fed group in the summer experiment and 16.6% greater in the spring experiment. Over the whole reproductive cycle the energy recovery in the creep-fed group was approximately 7% higher than in the group not receiving creep.

General Discussion

In general terms the results of the two experiments reported here have shown that the provision of supplementary feed to suckling pigs resulted in heavier litters at weaning and that the dams of litters receiving no supplements produced more milk over the last four weeks of lactation and lost more weight. This was especially true of the second-litter sows used in the second experiment. Finally, it was indicated that the intake of supplementary feed by the litter led to an increase in the energetic efficiency of litter production. This last conclusion requires further comment.

It is fairly certain that the estimates of the energetic efficiency of both lactation and the whole reproductive cycle underestimate the improvement due to creep feeding. In the methods of calculation used, the energy content of the litter was regarded, in Method A, as the whole outcome of lactation or the reproductive cycle, while, under Method B, the litter energy plus the change in sow tissue energy content were regarded as the outcome. The values used in estimating the tissue energy content of both creep- and non-creep-fed pigs were 420 kcal/lb liveweight at birth and 1,055 kcal/lb at eight weeks. Since the sows and litters in both groups in both experiments were treated similarly throughout gestation and up to three weeks of age, there is no reason to suspect that the energy content per pound differed between groups at birth and at three weeks. A very great difference in both weight and condition was obvious between the creep-fed and non-creep-fed pigs at weaning, however. After the fourth week of age, the non-creep piglets lost their bloom, became rangy, coarse-coated and thin, while their creep-fed counterparts were always fat and glossy.

There is little doubt that the weight increase of the creep-fed litters between three and eight weeks of age contained more fat and more energy than the weight increase of the litters not receiving creep feed. It is probable, therefore, that the efficiency values calculated for these latter groups were too high.

Previous work (Smith 1960a) has indicated that sows which lose weight during lactation are energetically less efficient than those which maintain or increase their weight. The higher efficiency of the creep-fed groups in the present experiments, therefore, is derived from two sources: (a) the lower weight losses of the sows; and (b) the greater efficiency with which the creep-fed energy obtained directly from the trough was converted to weight gains by the litter compared with the feed energy which was fed through the sow to produce milk for the suckers. Increased efficiency of energy conversion over the reproductive cycle can, therefore, be achieved through reducing sow weight losses and by increasing the proportion of the total feed intake of the sow and litter which is consumed directly by the piglets from the trough.

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Rhizobium INOCULATION OF LUCERNE (*Medicago sativa* L.)

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Summary

The *Rhizobium* content of commercial inoculants has been increased since the time these preparations were introduced to replace the formerly used agar cultures. Regardless of the presence of other organisms, the powder inoculants now in use are effective in lucerne nodulation and nitrogen fixation. No benefit was demonstrated in favour of disinfection of lucerne seed prior to inoculation, while in seed pelleted with lime there was a decline in the survival of rhizobia over a 3-months' period.

In a number of soils where lucerne establishment in the past has failed it has been shown that indigenous lucerne rhizobia (*Rhizobium meliloti*) were absent or ineffective, in sharp contrast with the abundance and nodulation efficacy of *Rhizobium trifolii* on subterranean clover. In some of these soils lucerne was established by the inoculation of seed with effective rhizobia, aided by raising the soil pH with lime applications and the use of inoculated seed, pelleted with lime or magnesium.

Among seven varieties of lucerne different responses were obtained to inoculation with single strains of *R. meliloti,* but the use of multi-strain commercial cultures achieved satisfactory nodulation and growth of these varieties.

Introduction

Inoculation of lucerne seed using cultures of nitrogen-fixing bacteria *Rhizobium meliloti* prepared by the Plant Diseases Division (P.D.D.), Department of Scientific and Industrial Research, commenced in 1928. In that season 7,000 lb of seed were inoculated. By 1955 farmers applied for cultures sufficient to treat 575,000 lb of seed (N.Z. Dep. sci. industr. Res. 1956). In 1956 the supply of P.D.D. cultures as single strains of *Rhizobium meliloti* on agar slopes ceased, and the service has since been conducted by commercial interests using dry or powder inoculants; the market is dominated by two organisations, one supplying cultures of New Zealand origin, the other distributing American cultures. The New Zealand organisation, Biological Laboratories Ltd., still prepares agar cultures, and supplies these as required. The powder inoculants are prepared in the manner discussed by Newbould (1951): suspensions of root-nodule bacteria are developed in aerated liquid nutrients, then mixed with neutralised fillers, usually peat or humus. During the first two years of use of these commercial cultures in New Zealand, several instances of failure of root nodulation were reported and examined. Evidence was obtained that some failures were associated with poor quality inoculants of either low total *Rhizobium* content or diminished vitality. Since then these low grade inoculants have disappeared from the market. An-

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other limiting factor at the outset was failure of powder cultures to adhere to seed. Commercial inoculants are now generally recommended for use with a sticker or "sticking" agent or with adherence assisted by lime pelleting. (Loneragan *et al.* 1955) (Bergersen and Brockwell 1958). Evidence is offered hereunder that there has also been a marked improvement in the rhizobial content of cultures. After all, the new materials introduced in 1956 presented problems of techniques in use, and the work of several extension workers has since aided understanding of the problems to be surmounted. (Sears, Hyde, and Greenwod 1955) (Lobb 1959).

Lucerne, with an acreage of over 100,000, is a highly important crop in New Zealand farm economy, and on several areas in Canterbury, where the greatest acreage is grown, difficulties are still experienced in getting the crop established. This investigation aims to examine some of the issues that may be connected with these difficulties, specifically properties of the *Rhizobium* cultures, lucerne establishment in problem soils, and the manner in which the range of lucerne varieties may respond to inoculation by the nitrogen-fixing bacteria.

Studies on the Effectiveness of Cultures of *Rhizobium meliloti*

An analysis, in broad categories, has been made of the microbial content of representative samples of commercial cultures now in use. The occurrence of micro-organisms in these was determined by standard agar plate techniques, using an agar, based on Vincent's (1958) broth medium for counts of *Rhizobium;* acidified potato dextrose agar for fungi and glucose-asparagine agar (Waksman 1950) for Actinomycetes.

Results of these analyses are shown in Table 1.

TABLE 1. Organisms per Microgramme of Commercial Grade Powder Inoculant

Inoculant	Rhizobium	Other Bacteria	Fungi	Actinomycetes
A (1955-56)	2	340	5	120
B „	4	90	3	110
C „	20	40	2	30
D „	60	110	1	70
C (1959-60)	340	5	0.3	8
D „	260	0.05	0.2	0.6

The cultures used were not the fresh, new stock preparations supplied by manufacturers. They were obtained from retail distributors in order that a sampling could be made of material on offer to farmers at the time. The figures in Table 1 show that only cultures C and D of those types available in the first year of supply by commercial interests showed a count of viable *Rhizobium* exceeding

20 million per g. By 1959-60 the cultures C and D supplied the New Zealand market—the other two types, A and B, originating in Australia, being no longer in circulation; and it will be noted that in the intervening period there had been marked augmentation of *Rhizobium* numbers in the preparations. In New Zealand, certification of the quality of legume inoculants is under the control of the Plant Diseases Division, Department of Scientific and Industrial Research (Hastings 1956), and initially the scheme of testing the cultures for efficiency was based on the quality and efficacy standards suggested in Australia by Vincent (1954). Of the more extensive testing of cultures by the Plant Diseases Division, Hastings (pers. comm.) has said that "counts of commercial inoculants have varied considerably but we have used as a standard a count of 100 million rhizobia per gramme of peat. Now, however, after five years, it is the intention considerably to raise the certification standards . . ."

On the evidence of Table 1 the earlier (1956) cultures were sub-standard, while those most recently available were satisfactory in terms of *Rhizobium* content. The significance of the profuse contaminant micro-flora is discussed later in this paper.

In this phase of the investigation, counts of viable *Rhizobium* have been made at intervals after receipt of cultures. By sampling at monthly intervals a steady decline in *Rhizobium* numbers has been recorded, but for four months after receipt of culture of C and D claimed by distributors to be fresh the count of *Rhizobium* bacteria has been maintained above 100 million per g. The margin set by the expiry date specified with the cultures appears to be safe.

Unlike the agar preparations formerly used, which were uncontaminated single-species cultures of *Rhizobium meliloti,* the powder cultures, on the evidence of Table 1, have a variable but relatively high component of other bacteria, fungi and actinomycetes, acquired during preparation and in the use of unsterilised peat fillers. Leonard (1944) has shown that such contaminant organisms do not appear to affect the efficiency of *Rhizobium* bacteria in nodulation or nitrogen fixation, but it seemed desirable to put this to test with the materials available in New Zealand.

Experimental

Inoculated and non-inoculated seed was sown in waxed cardboard pots containing 500 g of steam-sterilised soil. Prior to inoculation the lucerne seed (Marlborough variety, N.Z. certified strain) had been surface-sterilised by rinsing in ethyl alcohol 95% and by immersion in mercuric chloride 1/1,000, 15 minutes, followed by repeated washing with sterile water. These seeds were brought in contact with agar or powder cultures, and sown lightly in the prepared soils which were watered thereafter as required. The cultures used were the 1956 series now known to be lower in rhizobia than the 1960 series. After emergence seedlings were thinned to four per pot, two pots per treatment. The plants were lifted at 60 days by washing them from the soil in a jet of water over a screen. Because of the

difficulty of separating root systems, the stem and leaves only were analysed, nitrogen determinations being done by Kjeldahl procedure, after drying to constant weight. The results are presented in Table 2.

TABLE 2. NITROGEN-FIXING CAPACITY OF MULTI-STRAIN AND CONTAMINATED POWDER CULTURES OF *Rhizobium*

Treatment	Viable *Rhizobium* Colonies Per Microgramme	Percent Nitrogen in Dry Matter	M.grammes Protein in Dry Matter	Percent Inc. in Protein over Control
Powder				
Culture A	80	2.89	169.4	74.3
B	50	2.69	110.6	13.8
C	170	2.83	152.4	56.8
D	70	2.82	123.4	26.9
Control: no *Rhizobium* Inoculation		2.54	97.2	
Check Single species Agar culture				
1		2.74	136.1	40.0
2		2.82	145.5	49.7

The figures in Table 2 only serve to give a general indication, for the powder cultures were of relatively low *Rhizobium* content (1956 lines), not typical of inoculants now in use. Whether the contaminant microflora in these inoculants may induce microbial antagonism and impair the activity of associated rhizobia in the manner shown by Hely *et al.* (1957) to occur in soil and rhizosphere is not known. Despite the presence of other organisms the data in Table 2 indicate that the *Rhizobium* inoculants, A and C in particular, were satisfactory in terms of their ability to fix nitrogen in plant tissue. In fact, these powder inoculants, containing as they do several strains of *Rhizobium meliloti,* were more effective in this respect than the two single-strain agar cultures used in the comparisons.

Disinfection of Seed

In addition to the contaminant microflora of the peat filler used in cultures, the rhizobia, when applied to lucerne seed, can be expected to encounter the influences of contaminant organisms on the seed coat. The population of organisms on the seed coat varies quantitatively and qualitatively, and it is possible that the efficacy of *Rhizobium* in becoming established symbiotically with the roots of lucerne seedlings may be influenced by the numbers and nature of organisms on seed and thereafter in the rhizosphere.

Experimental

Samples of newly-harvested seed, Marlborough strain, were obtained from six farms on diverse soil types in Canterbury and Marlborough; and, from wash suspensions of the seed, agar plate counts of organisms per microgramme of seed were recorded as follows:

Waikuku	496
Dillon's Point	96
Hillersden	175
Waitaki	262
Hakataramea	402
Alexandra	228

Portions of this seed were then disinfected using alcohol and mercuric chloride, and the respective portions, disinfected and non-disinfected, were then inoculated separately with four single strains of *Rhizobium meliloti* known to be effective in nodulation. The treatments were sown in boxes of steam-sterilised soil and also in a field plot of low nitrogen status.

Measurements were made of stem length and degree of nodulation of the developing lucerne plants, but no differences were recorded among the *Rhizobium*-inoculated lines, either on sterile or non-sterile seed. From the observations it was concluded that seed inoculation can proceed as in the past, by application of the inoculant to non-disinfected seed, and there appears to be no need in field practice to rid the seed of contaminant organisms before inoculation.

Survival of Rhizobia on Lime-Pelleted Seed

The technique of pelleting legume seed with lime appears to have value in reducing detrimental effects of acidity in the close vicinity of germinating seed, and also in providing small or light seed with an augmented bulk that facilitates distribution, e.g., aerial sowing on unploughed land.

For lime pelleting and inoculating seed, an approved glue can be diluted 1:3 in warm water, then mixed with seed at the rate of one part by weight of glue with 10 parts of seed. Alternatively, methyl cellulose can be used as the sticker, and it is believed to give better results than any glue that may contain preservatives inhibitory to rhizobia. After this mixing the powder inoculant is added and mixed again. Finely ground and dry lime (dry lime flour) is then added and mixed in equal parts by weight of seed; or the inoculant can be added at the end of the process, after the seed has been pelleted with lime. The question then is, for how long can such inoculated seed be stored and remain effective?

Four inoculants were used in pelleted seed, and counts of *Rhizobium* were made at the outset of the treatment and at intervals thereafter. Results of agar plate counts of water suspensions from this seed were obtained as follows:

Rhizobium Count per g of Pelleted Seed

Inoculant	Initial	1 Month	2 Months	3 Months
A	56×10^7	73×10^4	65×10^3	19×10^3
B	66×10^7	481×10^4	450×10^3	105×10^3
C	29×10^7	76×10^4	19×10^3	11×10^3
D	82×10^7	60×10^4	12×10^3	9×10^3

These figures indicate that the effectiveness of a high *Rhizobium* count at the outset can be rapidly dispersed within three months of storage of pelleted seed. A number of factors could be relevant here, including toxic properties associated with some types of glue; but, as heavy rates of inoculation with *Rhizobium* are usually desirable (Sears *et al.* 1955), it is suggested that pelleted seed be sown as soon as possible after preparation.

Inoculation in Problem Soils

Experimental

A number of soil samples was obtained from areas where lucerne establishment was reported to be difficult, or where failures had occurred. In order to record the status of these soils in terms of naturally occurring rhizobia the samples were sieved and given a basal treatment equivalent to a ton of calcium carbonate per acre. As a check against the natural occurrence of the clover rhizobia (*Rhizobium trifolii*), seed of Subterranean clover, variety Mount Barker, was sown in these soils in comparison with Marlborough lucerne. To ensure the removal of possible seed-borne rhizobia, whose presence could mask the effect of indigenous strains of the organism present in soil, the seed was sterilised after the manner of Ash and Allen (1948), viz: immersion in 95% ethyl alcohol 15 minutes, 1/300 mercuric chloride 30 minutes. Disinfected seed was then planted on agar and bacteria-free germinating seeds later sown in duplicate pots containing 300 g of the prepared soil. Four plants were finally retained in each pot, and after 60 days these were washed free of soil and the nodules excised and weighed dry (24 hours at 105°c). Results are given in Table 3.

TABLE 3. Nodulation of Lucerne and Subterranean Clover in Problem Soils

Soil	Initial pH (Before Liming)		g Weight of Nodules per Plant after 60 Days	
			Lucerne	Subterranean Clover
	(in.)			
Eyre	0–1	5.2	Nil	0.92
	1–3	5.2	,,	0.94
Pukaki	0–1	6.1	,,	1.32
	1–5	6.5	,,	0.92
Culverden	0–1	5.2	,,	0.35
	1–3	5.5	,,	0.74
Wither Hills	0–1	5.0	,,	0.22
	1–4	5.2	,,	0.24
Moutere	0–2	4.8	,,	0.26
	2–4	4.7	,,	0.26
Coleridge	0–1	5.8	,,	0.38
	2–4	5.6	,,	0.61

Subsequently the trial was repeated with the lime application increased to the equivalent of 3 and 5 tons per acre. Similar results were obtained: prolific development of *Rhizobium trifolii* nodules on Subterranean clover plants, but no nodulation in these soils on lucerne.

It seemed therefore that these soils carried indigenous rhizobia capable of nodulating clover, but that they were devoid of effective nitrogen-fixing bacteria for lucerne. This abundance of clover rhizobia, and relative scarcity or absence of the appropriate lucerne organisms, had also been demonstrated by the work of Crozier (1953) when 19 soil types in Canterbury were sampled.

An observation was made, however, in some of these soils, where the pots at the end of three months had apparently become contaminated with air or water-born rhizobia, that good nodulation of lucerne did occur on roots at the base of the pots near the drainage opening. It would be assumed from this that, in the presence of an effective nitrogen-fixing strain of *Rhizobium,* and with the soil pH near optimum, nodulation could in fact be achieved. The soils in their natural state, and despite the absence of effective rhizobia (Table 3), should be able to support lucerne growth, provided inoculation with an effective strain of *Rhizobium* can be induced to succeed. This was examined through a trial designed to facilitate the establishment of a proven (effective) strain of *Rhizobium meliloti* on plants sown in these soils.

Experimental

Five of the soils were used. After being sieved, they were mixed with calcium carbonate on the basis of calculated lime requirement to bring the pH of each soil to 6.5. Pots containing 300 g of soil were set up. The treatments with Marlborough lucerne were: no inoculation; inoculation in lime pellets; inoculation in magnesium carbonate pellets (magnesium being an alternative to calcium as suggested by the work of Norris (1958)); inoculation without pelleting. The seed was inoculated by soaking in a 10-day broth culture of a strain of *R. meliloti* supplied by Dr L. Erdman, U.S. Department of Agriculture, earlier studies having proved this strain effective in nodulation. Inoculated seed was then pelleted in the manner described earlier, using, respectively, dry lime flour and magnesium carbonate, and sown in triplicate pots of soil.

There were no appreciable differences to be noticed between treatments during the early growing period. When plants were lifted at four months of growth, dry weights of stem and leaves were recorded as in Table 4.

TABLE 4. Lucerne Growth in Relation to Inoculation and Pelleting with Calcium and Magnesium

(Dry weight in g of six plants)

Soil	Control: No Inoculation	Magnesium Pelleting	Lime Pelleting	Inoculation Only
Culverden	0.014	0.026	0.028	0.037
Wither Hills	0.072	0.077	0.141	0.058
Eyre	0.788	1.255	0.804	1.141
Pukaki	1.338	1.771	1.703	1.653
Moutere	0.180	0.680	0.341	0.289

There was virtually no growth of lucerne for the Culverden and Wither Hills soil; it was therefore clear that, despite a pH level of 6.5 created by the basal lime treatment, together with the aid of lime or magnesium, some other factor was operating in these soils to preclude satisfactory lucerne development. The best plant development occurred in the Eyre and Pukaki soil, with the trend in favour of inoculation plus magnesium pelleting, but a statistical analysis failed to establish significance of the treatment differences. In the Moutere soil the treatment differences were highly significant:

	d.f.	m.s.	F
Treatments	3	.0929	46.0
Error	4	.0020	

In the breakdown of treatment effects in Moutere soil, magnesium pelleting was shown to be better, to a highly significant degree, than each of the other treatments. and, in addition, lime pelleting was proved to be significantly better than no inoculation.

Obviously the answer to the difficulty of establishing lucerne on the problem soils has not been fully elucidated—certainly not in the Wither Hills and Culverden types. In the other three, raising the pH to 6.5 and aiding nodulation by the use of lime or magnesium pelleting has been helpful. In associated work at Lincoln, Chee (1959) has conducted comprehensive trials in the Coleridge soil (pH 5.5), and found no inoculation response in lucerne sown in this soil which had previously received a basal dressing of phosphate and sulphur, unless a heavy application of lime had been made and the inoculated seed was also pelleted. Chee's data as summarised below showed no inoculation response of lucerne in the absence of lime, nor any significant response to molybdenum in this acid soil in the absence of supplementary lime.

Dry Matter Yields in Grammes

Lime Rating	No Inoculation	Inoculation
L0	.24	.73
L1	.52	3.09
L2	.91	3.00
	No Molybdenum	Molybdenum
L0	.48	.52
L1	1.63	1.90
L2	1.79	1.98

Pending further work on this aspect it seems that the approach to improved lucerne growth on these acid soils (Table 3) must continue to lie in the use of heavy dressings of lime. This feature has been fully examined and discussed independently by Norris (1959) and Loneragan (1959), from whose work it seems that the apparent benefit of liming is associated with any one of four possibilities:

(1) The need for calcium in the nitrogen metabolism and nodulation of the legume.

(2) The effect of lime in rendering molybdenum more readily available to the symbiotic system in the nodule.

(3) The neutralisation of soil acidity that in itself is detrimental to acid-intolerant rhizobia.

(4) The rendering of magnesium available through cation exchange—and it is the magnesium more than the calcium, according to the experiments of Norris, that is vital.

Differential Response of Lucerne Varieties

In recent years a range of lucerne varieties, additional to the widely grown Marlborough type, has engaged interest in New Zealand. The work of Palmer (1959) deals with a diversity of material that is available to provide for specific agronomic uses. As strains of *R. meliloti* vary in their nitrogen-fixing capacity and nodulation, it seems that strains of *Rhizobium* used in inoculants should be tested for efficacy as symbionts with individual varieties of lucerne.

In a preliminary trial an intimation was given that varieties can react at different levels to inoculation. Sterilised seed of the varieties Hunter river, Marlborough, Grimm, Provence, and Glutinosa was inoculated using *Rhizobium* strain 3 D On 3a (L. Erdman, U.S. Department of Agriculture), and sown in Coleridge soil that had been limed to bring the pH to above 6.0. The length of stems of three plants from each series was recorded as follows after three months grown under glass:

	Rhizobium Inoculation (In.)			No Inoculation (In.)		
Hunter river	9½	8½	9½	3	3	4
Marlborough	5	5	6	1½	1½	1½
Grimm	8½	5½	6	3	3	2½
Provence	8½	9½	8	9	6	10
Glutinosa	4½	5	5	6	5½	6½

The varieties Hunter river, Marlborough, and Grimm appear to have responded to inoculation with the specific *Rhizobium* strain, but not so the varieties Provence and Glutinosa. Several factors may be involved, and it seems likely that Nutman's (1946) findings in regard to clover parallel those of the *Medicago* group. He has shown in this and later work that clover plants possess genetic factors expressed either as resistance to infection by *Rhizobium* or ability of the host plant to establish the state of symbiosis with *Rhizobium* strains.

That the physiological state of lucerne differs among varieties has been denoted by the microbial counts as between rhizosphere of lucerne roots and the adjacent soil. Plants were grown in soil pots, and at intervals these plants were carefully detached from the soil and the roots transferred to 0.85% sterile saline and rotated. This comprised the rhizosphere dilution, transfers of which were made on to yeast extract (bacteria) or prune agar (fungi), both DIFCO Media. This suspension was filtered, and the resultant soil air-dried and weighed in order that the counts of bacteria and fungi could be expressed in relation to the weight of rhizosphere soil. In comparison

with this, the soil count beyond the rhizosphere was obtained by suspending portions of soil from the pots free of lucerne roots, followed by plating. Based upon this procedure, discussed more fully by Blair (1952), the rhizosphere : soil ratios for lucerne plants were obtained as expressed in Table 5.

TABLE 5. ORGANISMS IN THE RHIZOSPHERE OF LUCERNE

Variety	Yeast Extract		Prune Agar	
	Rhizosphere Numbers (Per microgramme)	Rhizosphere: Soil Ratio	Rhizosphere Numbers (Per microgramme)	Rhizosphere: Soil Ratio
Hunter River:				
spring (*)	7.7	3.7	6.8	2.8
summer (**)	4.2	3.2	3.9	2.1
Marlborough:				
spring	16.2	7.7	10.6	4.4
summer	7.2	5.5	6.7	3.7
Grimm:				
summer	3.2	2.5	2.4	1.3
(*) Control soil:				
spring	2.1		2.4	
(**) Control soil:				
summer	1.3		1.8	

On this basis, therefore, a more detailed study was made of the reaction of a range of lucernes to *Rhizobium* cultures.

Experimental

In the first trial *Rhizobium*-inoculated seed was sown on to sterile sand held in two-pint milk bottles, the system being irrigated with Crone's nutrient solution of inorganic salts but devoid of nitrogen (Bryan 1922) plus trace element solution. Growth of lucerne seedlings in this system would therefore be a reflection both of the nitrogen-fixing power of the strains of *Rhizobium meliloti* used in inoculation and of the response of the varieties to the specific strains. The results obtained are given in Fig. 1, which shows the mean length of stems of four plants in cm., and in Fig. 2, which shows the mean dry weight of four plants in g.

The evidence of Fig. 1 indicates that the differences in stem length in favour of inoculation were slight, but from Fig. 2 it appears that there were sharper differences in weight of tissue. Length of stem could not be a good criterion because of the enclosed glass system of the bottle containers used and because of the fact that, within the range of varieties used, there were sharp differences in growth habit of the lucernes of different genetic origin. The weight differences should be a better reflection of growth in the presence of nitrogen-fixing bacteria because differences should be more accountable on the basis of numbers of leaves formed on the plants. Fig. 2, for instance, shows that the varieties Hunter River and Du

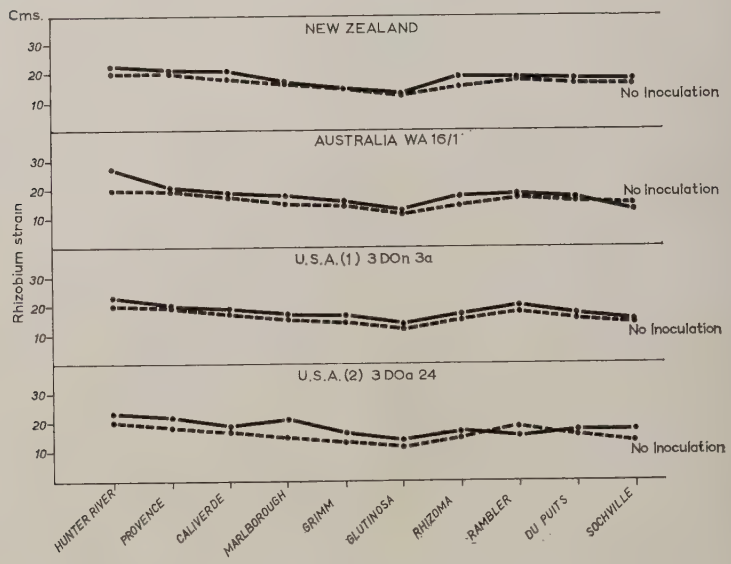

Fig. 1.—Lengths of stem in lucerne varieties inoculated with four strains of *Rhizobium meliloti*.

Puits responded more or less equally to the four inoculants but that varieties like Glutinosa, Caliverde, Marlborough, and Grimm gave higher weight increases under the influence of one specific strain of *Rhizobium*.

The trial was then repeated on another plan using a range of inoculated varieties grown in cartons of sterile sand. The lucerne seeds were sterilised in the manner previously described, followed by numerous washings in sterile distilled water. They were then transferred asceptically to agar plates and incubated at 28°c for 72 hours as a check to confirm the absence of contaminating organisms. Waxed paper cartons (2 lb) were prepared containing 400 g of river sand which had been washed, dried, and autoclaved for two hours at 15 lb pressure. About 12-14 sterile seeds from the agar dishes were planted in each carton about $\frac{1}{2}$ in. below the surface, and these were inoculated with 0.5 ml of a broth culture of the appropriate *Rhizobium* strain and covered immediately with sand. The pots were watered with distilled water when required, and once a week received 50 ml of the nitrogen-free solution of mineral salts and minor elements. The seedlings were later thinned out to six or eight plants in the 1959 and 1960 trials respectively. The plants were cut at 12 weeks, and the tops dried at 100°c for 18 hours, and dry weights obtained for analysis. An attempt to obtain the dry weights of the nodules was abandoned because of the difficulty in removing many minute nodules from the root systems. Results of the 1959 trial are given in Table 6.

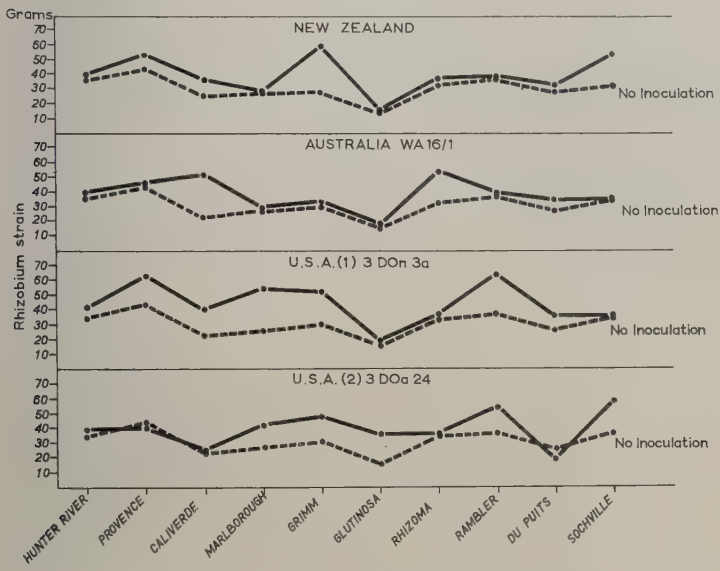

Fig. 2.—Dry weights of stem and leaf tissue in lucerne varieties inoculated with four strains of *Rhizobium meliloti*.

TABLE 6. RESPONSE OF LUCERNE VARIETIES TO 4 SINGLE-SPECIES CULTURES OF *Rhizobium meliloti*

Variety	*Rhizobium* Strain				
	No Inoc.	Dry Wts. of 6 Plants in g			
	O	A	B	C	D
Caliverde	.503	.610	.426	.712	.483
Du Puits	.166	.916	.516	.706	.763
Rhizoma	.260	.690	.330	.593	.526
Certified N.Z.	.440	.560	.530	.360	.326
Glutinosa	.255	.630	.310	.510	.565
Provence	.515	.605	.315	.475	.370
Hunter River	.255	.605	.355	.560	.440
Mean	.342	.659	.397	.561	.497

Key O = No inoculation
A = 3 DOn 3a L. Erdman, U.S. Department of Agriculture
B = WA16/1 Australia (through Biological Laboratories, Auckland)
C = P.D.D. Plant Diseases Division, New Zealand
D = 3 DOa 24 L. Erdman, U.S. Department of Agriculture

The variety Du Puits has been excluded from the analysis because of discrepancies between replicates in results within this variety. The varieties Caliverde, Du Puits, and Rhizoma were replicated three times in this experiment, and the other varieties had two replications.

Analysis

Between	*d.f.*	*m.s.*	*F*
Varieties	5	222.8	
Inoculum	4	1,673.8	
O*v* A,B,C,D	1	1,903.0	4.87†
A*v*B*v*C*v*D	3	1,597.3	14.09**
Var.x Inoculum	20	228.7	
Var.x(O*v*A,B,C,D)	5	390.4	3.44**
Var.x(A*v*B*v*C*v*D)	15	174.8	1.54 N.S.
Error	40	113.4	
	69		

The interaction of variety and inoculant was subdivided as shown. The variety differences between inoculants were consistent (F = 1.54), but the average response to inoculation showed highly significant variation from variety to variety. However, the individual inoculation treatments showed a response in all varieties except Provence, where inoculation failed in all but one of the treatments. Of the four different inoculants used only A and C are significantly above the control at the 5% level (one-sided test of significance). Comparisons between inoculants are more precise, and, by applying Duncan's test, C was shown to be above B (1% level of significance), A above B and D (1%), and C above D (5%).

In the 1960 trial the same seven lines of seed were used, and the techniques outlined above applied in preparation. There were again four different inoculants: two were single-strain cultures of *Rhizobium,* selected from the previous trial (A and B) as being apparently the most and least effective strains respectively; and two (E and F) were mixed commercial peat preparations. The peat inoculants were well shaken with sterile distilled water (2 g per 100 ml) and 0.5 ml pipetted on to each seed as before.

The results are shown in Table 7.

Analysis

The replicates of the varieties N.Z. Certified, Du Puits, and Caliverde showed marked variation due probably to glasshouse contamination, and these were omitted from the calculations to give a more precise analysis. The following data were thus obtained:

Between	*d.f.*	*m.s.*	*F*
Total	39		
Inoculum	4	.88	7.3**
Varieties	3	.16	N.S.
I x V	12	.12	6.0
Error	20	.020	

The general response to inoculation is highly significant (tested against interaction of variety and inoculation), and the different

† Tested against interaction: significant at 5% level in one-sided test.

TABLE 7. RESPONSE OF LUCERNE VARIETIES TO 2 SINGLE-STRAIN AND 2 MULTI-STRAIN CULTURES OF *Rhizobium meliloti*

Variety	*Rhizobium* Culture				
	No Inoc.	Dry wts. of 8 plants in g			
	O	A	B	E	F
N.Z. Certified	1.54	2.07	1.93	2.13	1.35
Du Puits	1.18	1.98	1.43	2.03	1.65
Caliverde	1.01	2.04	1.29	1.92	1.72
Hunter River	0.99	3.27	1.55	1.86	1.64
Rhizoma	1.31	1.53	0.86	1.79	1.54
Provence	0.99	1.57	1.61	1.86	1.56
Glutinosa	0.91	1.56	1.22	1.93	1.43
Mean	1.13	1.87	1.41	1.93	1.55
Mean of last 4 vars.	1.05	1.76	1.31	1.86	1.54

Key O = No inoculation
A = 3 DOn 3a
B = WA16/1
E = N.Z. peat mixed culture
F = U.S.A. peat mixed culture

inoculants show a unique pattern of response from variety to variety, but variety differences are not sufficiently consistent to be significant in comparison with the interaction. There is, however, no significant variation between varieties in the difference between multi-strain inoculants E and F. With regard to the single-strain inoculants A and B, the culture A has been consistently better than culture B (except with the variety Provence); this result confirms that of the previous trial, when the behaviour of these two strains followed a similar pattern.

This work reported appears to support the view that lucerne varieties or strains do not react equally to rhizobia of any one specific physiological strain. That there are different levels of response among lucerne varieties has previously been demonstrated by Burton and Wilson (1939). They studied nine strains of *Rhizobium meliloti* on three lucernes, and measured the growth differences. They found, though, that the relationship was affected by environmental conditions that tended to mask the influence of the host plant. In a more recent study Erdman and Means (1953) studied the development of 21 strains of *R. meliloti* on three lucernes. The variety Du Puits showed good acceptance of most strains, and they suggested that this type of varietal compatability with a wide range of rhizobia could account for the agronomic adaptability of such a variety of lucerne to a diversity of soil conditions. In contrast, the experiments of Erdman and Means demonstrated that the Narraganasett lucerne was strongly specific for a limited number of rhizobia. In practice the use of multi-strain cultures (types E and F, above) seems to cope with differential responses of the lucerne varieties at present used in New Zealand, as the manufacturers of inoculants have ensured that their cultures contain several *Rhizobium* strains claimed to be efficient in root nodulation and nitrogen fixation.

The reason some single strains of *Rhizobium* fail to produce in lucerne varieties the measure of plant response associated with other rhizobia remains to be shown. This phenomenon is demonstrated by a comparison, in Table 6, of *Rhizobium* strains B, C, D and A in respect to Provence and Glutinosa, and, in Table 7, of *Rhizobium* strain B in general with all lucernes tested. The latter *Rhizobium* strain has been used with success in Australia, and is claimed to have a satisfactory capacity to produce root nodules and to fix nitrogen. The nature of metabolites exuded by roots of the range of lucernes studied in this investigation is likely to vary, on account of the physiological nature of the *Medicago* species from which the varieties have been derived. In this connection the species origins of the lucernes under study are, according to Iversen (1957): Provence, Hunter River, and Caliverde—from *Medicago sativa,* with a trace of *Medicago falcata*; Marlborough, Du Puits, and Grimm—*Medicago sativa* hybrids; and Glutinosa and Rhizoma—*Medicago falcata* hybrids. An operative factor could be the influences of the root metabolites exuded on the *Rhizobium*-lucerne symbiosis. This feature is now under investigation.

Acknowledgments

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THE ESTIMATION OF SEASONAL SOIL MOISTURE DEFICITS AND IRRIGATION REQUIREMENTS FOR ASHBURTON, NEW ZEALAND

I. SOIL MOISTURE DEFICITS

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(*Received for publication, 7 July 1960*)

Summary

Thornthwaite's method of calculating potential evapotranspiration was used as a method of estimating day-by-day soil moisture changes in the top 12 in. of the Lismore stony silt loam. This was carried out for the period September to April inclusive of all seasons from 1912–13 to 1955–56.

Drainage was calculated by assuming that, when the soil was at field capacity, rainfall received was lost as drainage. The mean seasonal rainfall was 20.30 in., drainage losses were 4.50 in., and, therefore, the mean "effective" rainfall was 15.80 in. A regression equation of drainage losses on rainfall was derived:

$$Dr = 0.63R - 8.29 \qquad R \geq 13.16$$

where Dr = drainage and R = rainfall.

The mean calculated soil moisture deficit for a month was used to describe the degree of dryness of that month. There was a high correlation between this and the mean monthly soil moisture percentage as determined by the gravimetric method.

Introduction

Agricultural hydrology investigations are sometimes limited by the relatively small number of years for which records are available. For example, there are not many areas where frequent soil moisture determinations have been carried out over more than a few years. A survey of 44 seasons in the Ashburton County, based on Thornthwaite's (1948) method of estimating potential evapotranspiration, carried out to determine the irrigation requirements of the area, has also yielded information on: (1) the occurrence of agricultural drought (Rickard 1960); and (2) changes in soil moisture deficits under non-irrigated conditions. Results from the latter are given in the present paper.

Method

The method of estimating potential evapotranspiration due to Thornthwaite (1948) provides a means of estimating changes in soil levels for past seasons, and requires only daily rainfall records once the initial relationship between temperature and evapotranspiration has been derived. The reliability of the Thornthwaite method has been established for the area under consideration (Rickard 1957; Fitzgerald and Rickard 1960). Daily rainfall records were available from 1912 onwards.

An average daily value for potential evapotranspiration was used for each month, and daily changes in the soil moisture deficit (referred

to hereafter as "deficit") were calculated from 1 September to 30 April for each season from 1912–13 to 1955–56. Evapotranspiration values were added together to give a cumulative deficit, the rainfall being subtracted. If rainfall greater than the deficit was recorded, the excess rainfall was assumed to percolate through the soil and be lost as drainage. Similarly, rainfall received on days when the deficit was zero was credited as drainage. It was considered that run-off would be a negligible factor on the flat, well-drained area concerned; if similar calculations were being carried out for areas where the infiltration rate was exceeded by the rate of rainfall, and run-off was known to occur, it would be preferable to credit some or all of the excess rainfall as run-off rather than drainage. In either case, the basic assumption is that this excess rainfall is lost to plants growing in the area.

The deficit was not calculated to a greater value than 2.04 in., corresponding to permanent wilting percentage in the top 12 in. of soil, and when this deficit was reached it was maintained until further rainfall. It is not possible to use the estimated values of potential evapotranspiration to calculate deficits below the permanent wilting percentage, although soil moisture measurements have shown that deficits greater than this can develop.

RESULTS

Drainage Losses

The mean September–April rainfall for the seasons studied was 20.30 in., ranging from 36.28 in. (1952–53) to 11.74 in. (1914–15). The calculated drainage ranged from 16.17 in. in the former season to nil in the latter, with a mean value of 4.50 in. If the amount of drainage is subtracted from the total rainfall received, the "effective" or useful rainfall is obtained. During 1952–53, for example, approximately 45% of the rainfall was lost as drainage, and the effective rainfall for the season was 20.11 in. Table 1 shows the month-by-month means for rainfall and drainage.

TABLE 1. SEASONAL RAINFALL AND DRAINAGE

	Month								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
Rainfall (in.)	2.49	2.34	2.56	2.99	2.63	2.63	2.33	2.33	20.30
Drainage (in.)	1.36	0.67	0.42	0.44	0.32	0.51	0.38	0.40	4.50
Effective Rainfall (in.)	1.13	1.67	2.14	2.55	2.31	2.12	1.95	1.93	15.80
Drainage (%) Rainfall	54.6	28.6	16.4	14.7	12.2	19.4	16.3	17.2	22.2

September has the highest drainage losses. This is to be expected as the assumption is made that the month always commenced with the soil at field capacity. On the average, 54.6% of September rainfall is lost as drainage, and this percentage can in some cases be as high as 81% (1921). Drainage during October can still be high –70% of the

rainfall in 1953, with a mean for all seasons of 28.6%. Drainage for the remainder of the season (November–April) averaged 16% of the rainfall.

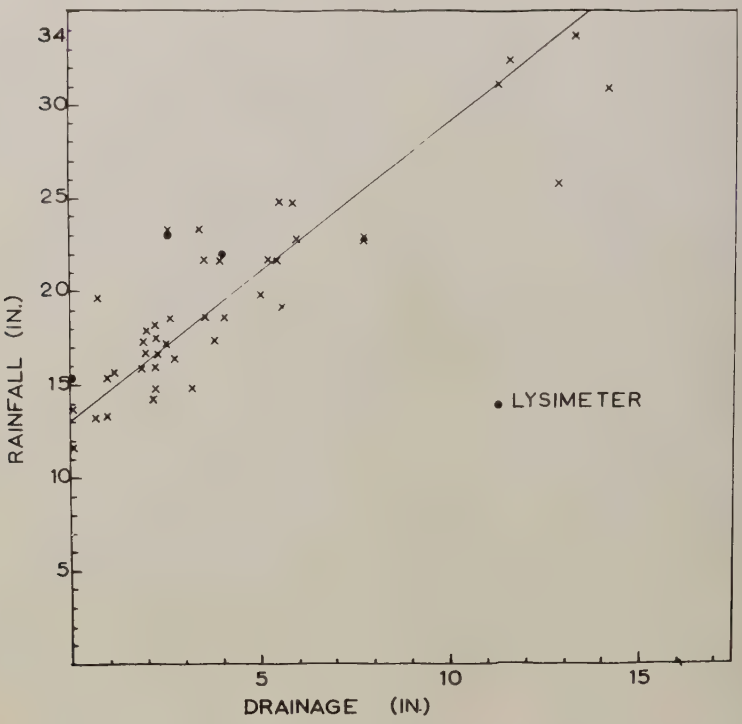

Fig. 1.—Relationship between seasonal rainfall and drainage, 1912–13 to 1955–56.

Seasonal rainfall and drainage figures are shown in Fig. 1. The regression equation of drainage losses on rainfall is:

$$Dr = 0.63R - 8.29 \qquad R \geq 13.16 \quad . \quad . \quad . \quad . \quad (1)$$

where Dr = seasonal drainage in inches, R = seasonal rainfall in inches. The correlation coefficient is +0.90. Some representative points from equation (1) are given in Table 2.

From equation (1) an expression can be derived giving the effective rainfall (Re) from the rainfall received:

$$Re = 0.37R + 8.29 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

It will be realised that the amount of drainage (and hence effective rainfall) will depend to a large extent on the distribution of rainfall throughout the season. In some seasons, therefore, a fairly wide divergence from equation (1) may be expected, e.g., during 1940–41, 25.78 in. rain fell, and the drainage calculated from equation (1) was

TABLE 2. RELATIONSHIP BETWEEN RAINFALL, DRAINAGE, AND EFFECTIVE RAINFALL

Rainfall (in.) (R)	Drainage (in.) (Dr)	Effective Rainfall (in.) (Re = R-Dr)	$\frac{Re}{R}$ (%)
13.16	nil	Re = R	100
15.00	1.16	13.84	92.3
20.00	4.31	15.69	78.5
25.00	7.46	17.54	70.1
30.00	10.61	19.39	64.6
35.00	13.36	21.24	60.7

7.95 in. However, the distribution of rain through the season was such that the drainage losses derived from a consideration of daily deficit figures amounted to 12.86 in. This was due to the fact that the September rainfall was heavy—5.60 in., of which 4.24 in. was lost as drainage, and the March rainfall was 10.6 in., of which 6.86 in. was drainage. In certain seasons, therefore. when exceptionally heavy rainfall occurs in some months, equation (1) can be expected to underestimate drainage losses.

An independent check on equation (1) is available from drainage measurements through an unirrigated massive lysimeter. Drainage is measured at a depth of 30 in. and records are available for three seasons under pasture. Results are shown in Fig. 1, and indicate a lower drainage than would be estimated from equation (1). There are two reasons why the recorded drainage may be expected to be lower. The lysimeters contain approximately 16–18 in. of soil and subsoil, plus 12–14 in. gravel and sand. The total deficit can, therefore, under dry conditions, be greater than the 2.04 in. assumed in the calculations and the capacity of the soil to absorb moisture before drainage commences is correspondingly greater. This fact has been demonstrated in irrigation experiments on a duplicate lysimeter. Also. records of actual soil moisture levels in the field have shown that, under dry conditions. a value lower than the permanent wilting percentage is reached. Consequently, even for a 12 in. depth of soil, a deficit greater than 2.04 in. is possible, and, under these circumstances, drainage would be less than calculated.

As noted by Seeyle (1946), rainfall in New Zealand tends to have an asymmetric distribution—there are more months drier than the mean than there are wetter than the mean. If the effective rainfall is used. both the seasonal and monthly distributions become more symmetric. Table 3 gives the distribution of "wet" and "dry" months for rainfall and effective rainfall.

The use of effective rainfall instead of rainfall eliminates the extremely high seasonal rainfall figures. The range is reduced from 24.54 in. (11.74 in. to 36.28 in.) to 9.10 in. (11.74 in. to 20.84 in.).

TABLE 3. DISTRIBUTION OF RAINFALL AND EFFECTIVE RAINFALL, 1912–13 TO 1954–55

	Rainfall*		Effective Rainfall	
	Drier Than Mean	Wetter Than Mean	Drier Than Mean	Wetter Than Mean
Number of months	209	142	182	170
Percentage	59.6	40.4	51.7	48.3

* One month equal to mean has been omitted.

Seasonal Changes in Soil Moisture

It will be seen from the foregoing section that, from an agricultural point of view, effective rainfall is a more accurate indication of the dryness of a month or a season than rainfall. Although the use of an estimated drainage loss eliminates rainfall which would not contribute very much to moisture conditions in the soil, the monthly or seasonal total of effective rainfall can still be of only limited value in describing the "dryness" or "wetness" of a period. For example, during the first 25 days or so of a month, rainfall may be low, and, as a result, the soil becomes particularly dry. Rainfall of 2–2½ in. in the last few days of a month may all be absorbed by the soil, and hence the total of effective rainfall for the month may be high, giving the impression of a month reasonably well supplied with moisture.

A complete picture of the soil moisture characteristics of a month or season is given by the day-by-day calculation of deficit. One of the

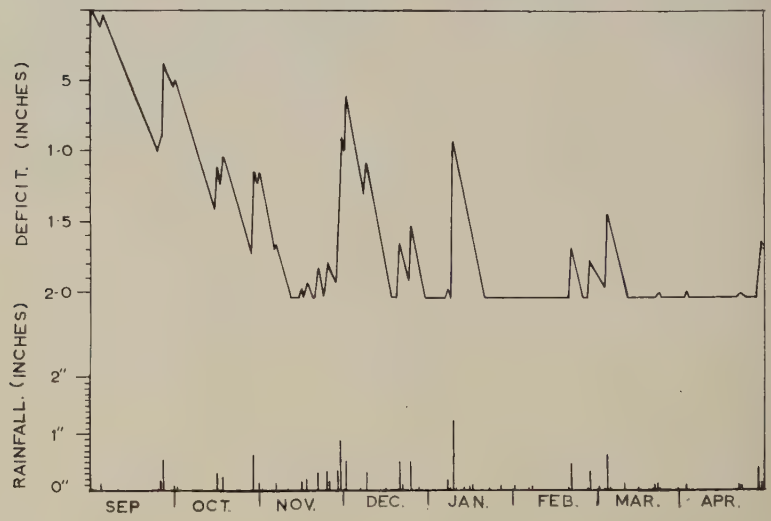

Fig. 2.—Soil moisture deficit changes, 1914–15.

driest seasons in the period covered by this survey was 1914–15, and the changes in deficit for this season are shown in Fig. 2. After 1 September 1914 the soil never regained field capacity; consequently, drainage losses were zero, and from mid-January to the end of April the soil was at (or probably below) wilting point for most of the time. Similar graphs of daily changes in deficit could be prepared for each of the 44 seasons studied.

Such information on different seasons can be condensed to a more convenient form by taking the mean deficit for each month. If this is done, the irregularity of the rainfall is taken into account and each month is given a value which is a reasonable estimate of the moisture status of that month. The four seasons with the lowest effective rainfall and the four seasons with the highest effective rainfall are shown in this form in Figs. 3 and 4.

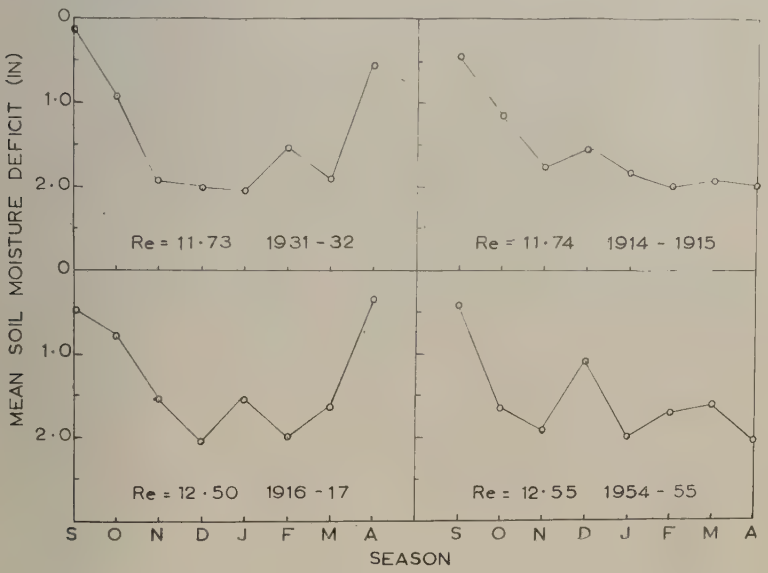

Fig. 3.—Mean monthly soil moisture deficits for seasons with low effective rainfall.

This method of delineating the soil moisture characteristics of each season is accurate and convenient. One season can be compared with another and the changes in soil moisture regime throughout any season seen at a glance.

To check the accuracy of using the mean calculated deficit for the above purpose, values for 59 months (September to April only) were compared with the mean *measured* soil moisture percentages for the same months. Gravimetric soil moisture determinations were made on the average about three times a week at the 0–4-in. depth. The results were graphed and the mean monthly soil moisture estimated by determining the

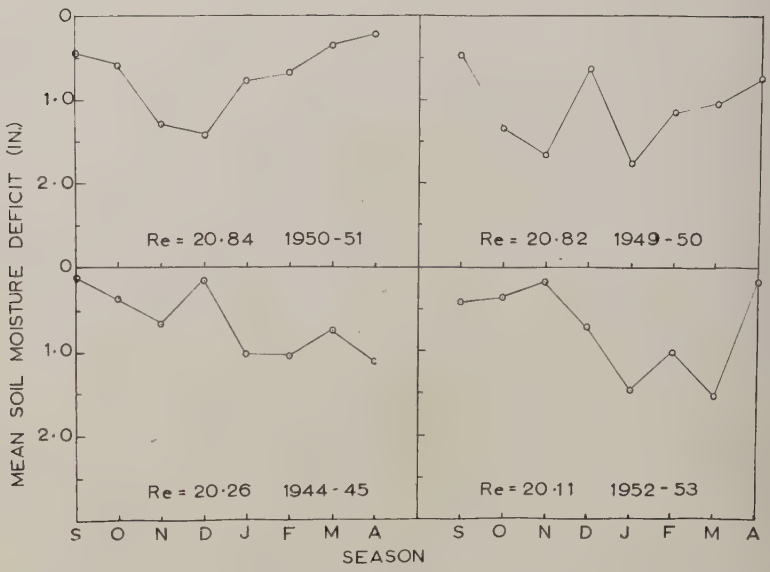

Fig. 4.—Mean monthly soil moisture deficits for seasons with high effective rainfall.

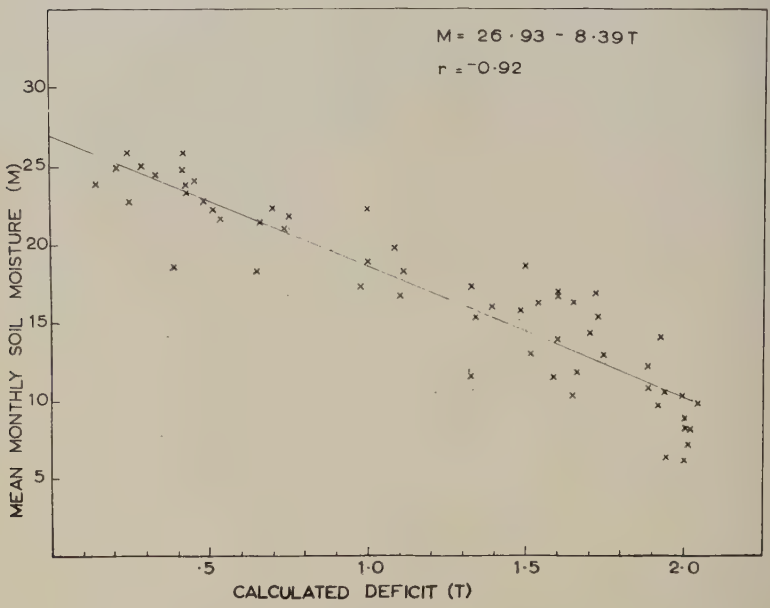

Fig. 5.—Relationship between mean monthly measured and calculated deficits.

area under the graph. Some of the months for which mean soil moisture percentages were available were later than 1955-56 (the last season of the survey) but were included to enable more data to be examined. Results are shown in Fig. 5. The regression equation of the mean measured soil moisture percentage on the calculated deficit is:

$$M = 26.93 - 8.39D_t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The correlation coefficient $r = -0.92$

where M = mean measured soil moisture percentage,

D_t = deficit in inches, calculated by Thornthwaite's method.

It is apparent from this that the mean calculated deficit can be used to derive the mean soil moisture percentage for any month in the period September to April.

It is interesting to note that equation (3) is almost the same as the experimentally determined relationship between soil moisture expressed as a percentage, and soil moisture expressed as inches per foot depth of soil. This is:

$$M = 27.00 - 8.33\ D_m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where

M = mean measured soil moisture percentage,

D_m = deficit in inches, measured.

CONCLUSIONS

Information on soil moisture and agricultural hydrology in past seasons can be obtained from the calculations of daily changes in soil moisture deficits. For this to be carried out, the following information is required:

(a) the reliability of the method used to estimate the deficit changes should be established for the area under consideration;

(b) the requisite meteorological data should be available.

In the present investigation, the Thornthwaite method was used, and mean monthly temperatures and daily rainfall figures from 1912 were available. Under these conditions, a useful tool is provided for the investigation of the following aspects of agricultural hydrology:

(1) calculation of day-by-day changes in soil moisture, enabling soil moisture graphs to be prepared for any past season;

(2) an estimation of the proportion of rainfall which is lost by drainage, and from this, an estimate of the amout of rainfall which is retained by the soil, and is therefore available for plant growth and transpiration;

(3) a measure of the average level of soil moisture deficit for any period—week, month, or season. This provides a more accurate indication from an agricultural point of view of the comparative "dryness" of periods, and may have application when such an estimate is required for long term studies of plant production or animal health.

Acknowledgments

Thanks are due to Mr P. D. Fitzgerald for calculating the regression equations.

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A SURVEY OF THE PATTERNS OF WHEAT GROWING IN CANTERBURY IN 1952 AND 1953

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Summary

Details are shown of the methods used in drawing a sample of Canterbury farms for a survey of wheat growing practices and yields, where the stratification was based on soil type instead of on the customary administrative units of counties. The frame of farms produced for this purpose may be of use to other workers wishing to survey the area.

Estimates of the areas of wheat grown in two consecutive years are found, with the sampling errors of such estimates for each district.

Most of the wheat was grown on medium land, although the percentage of farm land used for wheat was greatest on the heavy land.

Nearly 60% of all the wheat was grown either in the year after grass, or where one intermediate brassica crop had been taken after ploughing out of grass. No important yield effects could be ascribed to use of any rotation.

Introduction

In 1953 a survey was made of the pattern of wheat growing in Canterbury for that and the previous year, in which the sampling methods used were somewhat different from those of most of the small agricultural surveys carried out in New Zealand. The aims of this particular survey, performed by field officers of the Extension Division of the Department of Agriculture, were:

1. To provide background information against which a rational selection might be made of a panel of growers from whom further details would be obtained for a cost-of-production study.
2. To obtain detailed estimates of the acreages being grown on the different types of land, and the associated cultural practices, for general use in consideration of agricultural policy or advice.
3. To obtain estimates of the errors attaching to information obtained by means of surveys conducted on a sample of farmers.

The first aim provided the necessity for conducting the survey. The Department was required to make a detailed study of the cost of production of wheat for price-fixing reasons. In most previous cost studies it had been the practice to use a small panel of growers whose names had been supplied by the industry concerned and who were known to be willing and able to supply the necessary details. Unfortunately in such a sysetm there is no means of telling how typical such a panel is, or of what acreage each member can be considered the representative. Thus no weighting of information can be done in obtaining a composite cost related to the whole area.

The second aim was desirable because, in discussions of matters such as a decline in wheat acreage, reliance had always to be placed

on the "opinions" of where the main wheat-growing areas were and the relative importance of different factors. There is often little agreement among these opinions.

The first aim, though essential if a real improvement were to be made in the methods of obtaining costs, was not alone considered sufficiently important to warrant the expense of a full survey. It was decided, however, that the requirements of the second aim could be simultaneously met, and that, together, the two sets of information would be worth the cost. All estimates of wheat acreages available from other sources are based on administrative sub-divisions such as counties, and, consequently, give no information about the importance of the crop on different types of farms. The important difference in this survey was, then, that the land class (based on classified soil types) was used as the stratification basis.

Fig. 1.—Map showing approximate boundaries of areas covered by survey.

Most agricultural surveys are based on farmer co-operation rather than on statutory powers, and a critical appraisal was needed of the response rate that could be achieved in a survey based on random sampling, and also of the sampling errors involved. There was a growing desire to use the survey method in many inquiries. In this

TABLE 1. SOIL TYPES IN LAND CLASSES

Light Wheat Land	Medium Wheat Land	Heavy Wheat Land
L3 Lismore silt loam	Ch3 Chertsey silt loam	Cr 3p Crows peaty silt loam
E2 Eyre sandy loam	Co3s Coldstream shallow silt loam	Ht3 Hatfield silt loam (heavier rainfall)
E2-3 Eyre stony loam E3 Eyre silt loam	Ht2 Hatfield sandy loam	K3 Kaiapoi silt loam (North Canterbury)
Gy3 Garry stony loam	Ht3 Hatfield silt loam (lighter rainfall)	P2 Papanui sandy loam
W1 Waimakariri sands	Ly3 Lyndhurst silt loam	Rk3 Rakaia silt loam (heavier rainfall)
W2 t, T Waimakariri shallow stony loam	Lb2 Ladbrook sandy loam	
	Pr2 Paparua sandy loam	Sp3 Springston silt loam (all phases on higher rainfall)
Pr 2-3 Paparua stony loam	Rk2 Rakaia sandy loam (lighter rainfall)	
Ru3 Ruapuna silt loam	Rk3 Rakaia silt loam	T2,3,4 Tai Tapu sandy silt and clay loam
Ka3 Kakahu silt loam	Sp3s Springston shallow silt loam (lighter rainfall)	
N3 Ngapara silt loam		Tk3,4 Temuka silt, peaty and clay loams
NH Ngapara hill complex	Tp3 Templeton silt loam (lighter rainfall)	Tp3 Templeton silt loam (heavier rainfall)
Op3 Opuha silt loam OpH Opuha hill complex	W2 S,s Waimakariri sandy loam	W3 Waimakariri silt loam (North Canterbury)
Rp3 Rapuwai silt loam		W⅔ Waimakariri sandy loam on silt loam
RpH Rapuwai hill complex	Wt3S Waterton shallow silt loam	
Tk Temuka complex	W3 Waimakariri silt loam (South Canterbury)	Wd 5 Windermere peaty loam
To3 Taiko silt loam	W3S Waimakariri shallow silt loam	Wm5 Waimari peaty loam
		Pk3 Pukeuri silt loam
ToH Taiko hill complex	C3 Claremont silt loam	Wb3 Willowbridge silt loam
	K3 Kaiapoi silt loam (South Canterbury)	Wh3 Waihau silt loam Wh2 Waihau sandy loam

case the information sought was of a simple and straightforward nature, and it was the allotted task of each instructor in agriculture to visit a certain number of chosen farms and fill in the schedule by discussion with the farmers. No use was made of postal questionnaires. For these reasons the errors in information and the non-response rate probably represent the minimum likely to be encountered in such surveys.

Coverage of the Survey

The survey was meant to cover the land district of Canterbury, but areas where little or no wheat was grown were excluded. In order to define and sub-divide the area to be included, soil maps were superimposed on maps showing the boundaries of farm holdings. All holdings whose owners were on the electoral roll of the United Wheat Growers Association were marked. It was found that this list did not give an accurate list of wheat growing farms in any one year, hence it could not be used in drawing the final sample for the survey. But it sufficed to indicate which areas could be safely omitted from the survey, and where the natural boundaries were for the sub-districts.

The class of land was carefully defined, since wheat growing was to be studied relative to land class. Three different classes of land were recognised: light, medium, and heavy. These classes were specified entirely in terms of soil types of the recognised Soil Bureau classification, and the code abbreviations of the soil types comprising the classes are set out in Table 1. The soil types were allocated to one of the three classes, according to the normal expected yield, as follows:

	North and Mid-Canterbury	South Canterbury
Light Wheat Land	Under 35 bus. p.a.	Under 35 bus. p.a.
Medium Wheat Land	35–45 bus. p.a.	35–50 bus. p.a.
Heavy Wheat Land	Over 45 bus. p.a.	Over 50 bus. p.a.

At this time almost all the wheat grown in Canterbury was of the variety Cross 7, and these expected yields relate to that variety.

From the "landclass" maps drawn to the above definitions 19 major districts, containing 50 sub-districts, were delineated, each sub-district being a geographical unit containing one land class if possible. In a few cases sub-districts were intermingled, since there were patches of land on one class within a region that would otherwise have belonged to another class. Details are shown in Fig. 1, and an accurate description of the sub-division boundaries has been filed as a permanent record.

When the survey had been completed, the mean yields per acre of these districts for the year 1951-52 were estimated from the results, and the values are shown in Table 2. Most districts gave yields within the expected ranges, the main anomaly being places such as Kaiapoi and Amberley in the heavy group. The presence of considerable hail

TABLE 2. AVERAGE YIELDS, 1951–52, FOR DISTRICTS IN LAND CLASSES

	Bushels Per Acre
Light land districts	
Lauriston-Seafield	35.8
Ruapuna-Orari-Glenavy	34.3
Medium land districts	
North Canterbury downs	41.2
North Canterbury plains	39.1
Canterbury plains	37.6
Chertsey-Dorie / Methven-Rakaia	39.0
Greenstreet-Hinds-Waterton	47.5
Timaru plains	48.2
Timaru and Waimate downs	46.3
Waimate plains	44.2
Heavy land districts	
North Canterbury	32.1 (drainage problems, hail damage)
Canterbury plains	47.5
Barrhill-Winchmore-Methven	48.9
Lagmhor-Tinwald-Wakanui	43.5
Willowbridge	54.9

(Districts with less than 5 crops omitted.)

damage in this group reduced the yield. The acreage yield, excluding those fields where hail damage was specifically mentioned, was 38.4 bus. p.a. On some farms in this district, where the yield was low, poor drainage was specifically mentioned in the schedules.

Again, from these "land class-holdings" maps, all holdings within each sub-district were read off and listed, together with their acreages, which were obtained from the county lists held by the Lands and Survey Department. Where the sub-district boundary ran through any holding (because that holding contained two land classes), the acreage was split by observation of the map, and the holding entered in the lists of both districts, suitably marked, and with part acreage in each. This arbitrary splitting was not accurate, but the errors were likely to be random, and it was the most convenient way of avoiding boundary bias in the sample. Where information was available, from any source, that a holding was not a farm—the holding might be, for example, a golf course, a plantation, or a racecourse—it was omitted entirely from the lists. Since not all such ineligible holdings could be recognised, some may still be in the lists, but they will be gradually eliminated.

Although the labour involved in their compilation was considerable, these lists of farms should now be a most valuable frame of reference for drawing samples for any other farm study. In fact, since the original survey, they have been so used. They can be made available to anyone requiring them. Only minor changes will be

needed to keep the lists up to date, as change of ownership often leaves the holding boundaries intact.

Method of Obtaining the Sample for the Survey

From each sub-district a random sample of holding numbers was drawn, and the acreages recorded. Samples were drawn till just over 20% of the total area was reached. There was no weighting in proportion to acreage, each holding having equal probability. Note that, in assessing the "total area" for a sub-district, the sum of all the acreages in the frame list was used, there being no attempt to read the district total off the map. When a split holding (see above) was drawn in the sample it was not differentiated in the lists being sent out to the enumerator. The schedules were so designed that it was possible to sort out at Head Office that information relevant to the land class—and, hence, sub-district—which had been drawn, and merely to ignore that relating to the other part of the farm. This was possible because "overhead" items were to be used only in making sure that no farm highly atypical of its group would be included in the later detailed cost study. Thus, for the factors for which district totals were to be estimated, the sample was not biassed by wrong boundary probabilities.

Recording the Results

For all schedules received, the stated acreage and land class were checked against the entry in the original list, and those showing disagreement were discarded. Only slightly less than 1% of the schedules were so affected. All schedules were checked for internal consistency, and reasonableness of farm details, and for completeness of information. Again, the few unsatisfactory ones were discarded. As there was an urgent need to supply the information for the cost survey, there was no time to refer these back to the districts for correction, and, as the loss from these factors was only 1.6% in total, the cost of such action was not justified. Losses from other reasons were:

Information not available, because of death or change of ownership: 3.5%.

Information refused: 0.4%.

A further 74 schedules, representing 4.5%, were never received, with no explanation. This left the total number of schedules accepted for analysis at 1,452, i.e., 89.1% of the number drawn in the original sample. No replacements were allowed. At best, only a part of the other 10.9% could have been retrieved by much further effort, and this was not considered justified for such a return.

All information was analysed by standard Powers-Samas cards. The main factors studied were:

1. Area in wheat for 1951-52 and 1952-53.
2. The yields obtained.
3. The cultivations performed.
4. The rotation of crops in the field for the two years before the wheat crop.

For use in the costing selection, details of the stock carried and of other crops grown were also given. Varieties of wheat and manure used were recorded but showed so little variability that they were of no interest. At the time of the survey the yields of many of the crops for 1952-53 were not available, since the harvest had not been completed. Omission of this did not cause a schedule to be rejected as incomplete, and yields in 1951-52 only were analysed.

THE COSTING PANEL

When most of the schedules had been carded, preliminary estimates of the wheat acreages by districts were obtained and a choice made of eight sub-districts, from each of which one farm was chosen for the cost study. Each of these districts was sorted according to the sizes of the farms; and, from the groups containing the mode of the size distribution, about three farms were chosen, where the relative acreages of other cash crops and grass were somewhere near the average for the district. The costing officer then performed his further study on one of the three. Since not all farms have the necessary records available, nor all the farmers the necessary willingness to take part in such a study, the choice of the panel cannot be made too rigidly from records. This scheme seemed to have reduced the personal choice to the minimum, and to have ensured that the farms chosen were not wildly atypical of their district, at least in general structure. Perhaps they are all too close to the "average", but, with only eight to be included, this seems a preferable alternative. No replacements outside the original choice were necessary. The problems of the cost survey will not be further discussed here. The defect that farmers who keep good records may be more efficient than others has not been met, and this is a recurring problem with all cost studies.

RESULTS OF THE SURVEY

Estimation of District Totals

The area of wheat in a sub-district was obtained as:

$$\text{Area of wheat on all sampled farms in sub-district} \times \frac{\text{Total area of sub-district}}{\text{Total area of sampled farms in sub-district.}}$$

The area of wheat in each whole district was estimated by a similar method except that the word district replaced sub-district. The slight variations in sampling fraction for the different sub-districts were ignored. After the selection of the costing panel, the main interest centred on the districts, rather than the sub-districts, which were then only considered as strata for the sampling. All estimates were for whole districts.

Estimates of the Acreages

Table 3 shows the estimated acreages for each of the two years by districts, with the associated sampling errors, and also the percentage of the total farm area devoted to wheat growing. For all land classes

TABLE 3. ESTIMATES OF WHEAT ACREAGES, WITH ERRORS, IN DISTRICTS IN LAND CLASSES

District	Total Area (acres)	Acres Wheat in 1951–52	S.E.	Acres Wheat in 1952–53	S.E.	% of Farm Area in Wheat 1951–52	% of Farm Area in Wheat 1952–53
Light land							
North Canterbury	61,512	344	171	781	445	0.6	1.2
Canterbury plains	165,691	370	195	1,079	391	0.2	0.6
Lauriston-Seafield	119,459	2,848	765	3,420	665	2.4	2.9
Albury-Fairlie-McKenzie	60,020	119	84	196	43	0.2	0.3
Ruapura-Orari-Glenavy	140,698	761	282	1,395	409	0.5	1.0
Total	547,380	4,442		6,871		0.8	1.3
Medium land							
North Canterbury downs	130,494	3,245	608	6,832	890	2.5	5.2
North Canterbury plains	96,758	3,408	543	5,672	682	3.4	5.7
Canterbury plains	180,140	8,711	1,301	9,472	1,282	5.2	5.3
Chertsey-Dorie	57,043	2,869	505	1,794	470	5.0	3.1
Methven-Rakaia	70,642	6,176	731	7,186	684	8.7	10.2
Greenstreet-Hinds-Waterton	36,944	1,685	351	2,774	405	4.3	7.1
Timaru plains	82,183	2,595	503	3,292	722	3.2	3.9
Timaru and Waimate downs	183,433	8,474	871	9,602	931	4.6	5.2
Waimate plains	142,058	2,669	462	3,670	692	1.9	2.6
Total	979,695	39,832		50,294		4.1	5.1
Heavy land							
North Canterbury	67,504	1,289	295	2,776	420	2.2	4.2
Canterbury plains	66,764	1,477	369	3,768	766	2.3	5.8
Barrhill-Winchmore-Methven	47,501	3,961	549	5,016	768	8.2	10.4
Lagmhor-Tinwald-Wakanui	65,054	4,137	621	5,966	800	6.5	9.2
Willowbridge	24,893	1,393	317	1,577	416	5.6	6.3
Total	271,716	12,257		19,103		4.5	7.0
Total all classes	1,798,791	56,531		76,268		3.1	4.2

the area in wheat was greater in 1952-53 than in 1951-52, although this increase was greatest on the heavy land. This, then, gives no evidence to support the theory that low acreages of wheat are caused by less planting on the "marginal lands". Such areas would come into the "light" classification in our survey.

The districts where the proportion of farm area devoted to wheat was highest were in Ashburton county, namely, the heavy land of Barrhill-Winchmore-Methven, and the medium land of Methven-Rakaia. Other neighbouring districts, such as Lagmhor-Tinwald-Wakanui (heavy) and Greenstreet-Hinds-Waterton (medium), had higher-than-average proportions. In the same locality Lauriston-Seafield had easily the highest wheat/farm area ratio among all the light land districts.

This locality factor seems more important in determining the amount of wheat grown than does land class.

PERCENTAGE OF FARM DEVOTED TO WHEAT

	1951–52	1952–53		1951–52	1952–53
Ashburton districts	5.5	6.6	Light land	0.8	1.3
Remainder of survey	2.0	2.0	Medium land	4.1	5.1
			Heavy land	4.5	7.0

Comparison with Other Estimates

By recombining the sub-districts it was possible to make up areas corresponding to counties, and, for these, to compare the survey estimates of the wheat acreages with those published by the Department of Statistics. (See Table 4.) These published figures were obtained from the census returns in 1951–52, but from only a sample of farms in 1952–53. The sampling errors of the "county estimates" from this present survey were not calculated, but from the errors for districts quoted in Table 3 it is apparent that the deviations from the published figures are within expectations.

TABLE 4. ESTIMATES OF WHEAT ACREAGES BY COUNTIES

County	1951–52		1952–53		
	Survey	Census	Survey		Census
Cheviot	413	420	1,010		
Amuri	1,660	2,041	2,710	7,819	8,812
Waipara	1,894	1,828	4,099		
Eyre					
Oxford	2,319	4,043	8,242		
Rangiora					
Ashley				13,516	15,879
Malvern	4,564	4,795	4,636		
Selwyn	1,305	1,256	638		
Paparua	1,613	1,978	2,103		
Springs	456	695	879	8,868	8,802
Ellesmere	2,620	2,667	5,886		
Ashburton	22,437	23,993	27,169		28,619
Levels	6,661	6,018	7,108		6,914
Geraldine	2,567	3,536	3,809		4,353
Mackenzie	119	684	196		1,424
Waimate	5,903	5,929	7,606		10,445

Place of Wheat in the Rotation

The crops in the fields for the two years prior to the wheat crop were recorded on the schedules. These were arranged in 12 patterns, and the "rotation pattern" was thus coded for each field. As a guide to the dominant patterns in the districts, the numbers of fields in each pattern were counted. Table 5 shows that, for each district, two, or,

TABLE 5. NUMBERS OF CROPS IN THE MOST COMMON ROTATION AND CULTIVATION PATTERNS

District	Total No. of Fields	Rotations						Cultivations			
		1	2	3	4	5	6	A	B	C	D
11 Heavy land in North Canterbury	54	12	10	2	4	5	2	19	20	7	1
12 Heavy land in Canterbury plains	65	16	2	8	1	6	1	16	12	21	1
13 Barrhill-Winchmore-Methven	72	28	11	16	—	12	—	41	9	7	—
14 Lagmhor-Tinwald-Wakanui	79	22	4	4	2	20	—	24	19	19	—
15 Willowbridge	41	9	7	—	7	2	2	12	11	5	8
21 North Canterbury downs	92	19	31	5	—	7	8	10	52	20	—
22 North Canterbury plains	98	26	22	6	3	16	5	37	35	5	1
23 Canterbury plains	120	38	17	22	11	3	11	50	43	21	2
24, 25 Chertsey-Dorie-Methven-Rakaia	121	42	21	10	2	9	14	44	28	11	—
26 Greenstreet-Hinds-Waterton	41	12	8	2	—	5	2	16	12	9	—
27 Timaru plains	63	18	12	—	4	6	6	20	19	11	2
28 Timaru and Waimate downs	121	28	29	4	2	13	30	26	57	21	4
29 Waimate plains	69	14	19	—	4	2	15	13	29	20	2
33 Lauriston-Seafield	40	12	13	—	—	3	5	14	15	3	—
35 Ruapuna-Orari-Glenavy	18	4	8	—	—	—	2	4	11	1	1

Key:—

Rotations:
1. Grass, grass.
2. Grass, brassica.
3. Grass, peas.
4. Grass, potatoes.
5. Grass, any other crop.
6. Brassica, other crop.

Cultivations:
A. Skim ploughing, deep ploughing, grubbing or discing.
B. Deep ploughing, up to 3 grubbings.
C. Deep ploughing, more than 3 grubbings.
D. No ploughing, any number of grubbings, harrowings, or rollings.

at most, three, patterns covered most of the crops. Hence further study was confined to those patterns, with some groupings where desirable. Table 6 shows the percentage acreage in each of these major rotations, and the mean yield according to each. The sampling errors of the estimates were also calculated, and any apparent differences due

TABLE 6. ESTIMATES OF YIELDS OF WHEAT BY PRINCIPAL ROTATIONS IN SELECTED DISTRICTS

District	Crops Preceding Rotation	Yield Per Acre (bushels)	No. Crops	% of District
13 Barrhill-Winchmore-Methven	Grass, grass	49.8	14	49.9
	Grass, brassica	41.7	5	10.4
	Grass, other crop	49.3	12	29.8
14 Lagmhor-Tinwald-Wakanui	Grass, grass	43.0	11	35.3
	Grass, crop	46.7	15	43.6
22 Medium land, North Canterbury plains	Grass, grass	40.4	12	30.3
	Grass, brassica	40.9	11	28.9
	Grass, other crop	36.3	11	28.3
23 Medium land, Canterbury plains	Grass, grass	40.9	18	41.9
	Grass, peas	37.0	10	15.0
	Grass, other crop	35.0	19	32.1
24, 25 Chertsey-Dorie-Methven-Rakaia	Grass, grass	41.8	20	35.8
	Grass, brassicas	28.4	8	18.6
	Grass, other crop	40.4	10	19.9
28 Medium land, Timaru and Waimate downs	Grass, grass	40.7	12	19.6
	Grass, brassicas	55.3	15	23.7
	Grass, other crop	47.4	10	11.8
	Brassica, any crop	49.8	14	28.9
29 Medium land, Waimate plains	Grass, grass	51.6	8	26.9
	Grass, brassicas or brassica, other crop	45.2	13	42.9

to rotations were tested statistically. The sampling errors were mostly of the order of 3 bus. p.a. and the only effects to reach the 5% level of significance were:

1. The reduction in yield for rotation 2 (grass, brassica) in district 24 and 25.
2. The reduction in yield after grass (rotation 1), and the increase after grass, brassica (rotation 2), in district 28. These effects are contradictory; consequently, without further evidence, little emphasis should be placed on them despite their statistical significance.

Over all districts the two most common rotations were:

1. grass, grass, wheat; and
2. grass, brassica crop wheat, which cover 75% of the wheat crop acreage.

Cultivation Patterns

In Table 5 may also be seen the number of crops in the different cultivation patterns. A certain amount of grouping of the 12 original patterns was done. One of the most interesting comparisons the relative amount of skim ploughing in addition to deep ploughing may be obtained from the number in pattern A versus the total of patterns

B and C. This shows that it is in districts 24 and 25 (Methven-Rakaia-Chertsey-Dorie: medium land), and 13 (Barrhill-Winchmore-Methven: heavy land) that skim ploughing plus deep ploughing is a common practice. Districts showing a clear dominance of deep ploughing only are 21 in North Canterbury, and 28, 29, 35, all in Timaru-Waimate. This suggests that locality is again a more pronounced factor than land class in setting the practice. However, in districts 24 and 25, and 13, there were more wheat fields directly after grass than in other districts.

This relation between the cultivation practice and the place of wheat in the rotation may also be seen in Table 8. There the areas in the two most common rotations are split according to cultivation pattern in each land class. (Sub-division of the land classes into districts would have left too few crops in most cells of the Table.) This Table shows that, as excepted, cultivation A, which includes skim ploughing, is most commonly associated with the rotation where wheat follows grass. However, it is not exclusively so, and, as we progress from light to heavy land, there is an increase of the proportion of the area where

TABLE 7. Estimates of Yields of Wheat in Principal Cultivation Patterns in Selected Districts

District	Cultivation	Percentage of the District Wheat	Yield Bus. p.a.	No. of Crops
11 Heavy land, North Canterbury	A	46.9	24.8	9
	B	36.5	40.5	6
14 Lagmhor-Tinwald-Wakanui	A	36.6	40.4	12
	C	36.6	41.3	10
21 Medium land, North Canterbury downs	B	54.6	43.0	16
	C	21.8	31.1	6
22 Medium land, North Canterbury plains	A	37.7	39.1	12
	B	26.6	36.5	8
23 Medium land, Canterbury plains	A	50.9	42.9	21
	B	35.3	35.9	17
	C	18.5	33.9	10
24, 25 Chertsey-Dorie-Methven-Rakaia	A	56.7	39.1	24
	B	12.5	39.2	9
27 Medium land, Timaru plains	A	39.1	52.4	10
	B	30.2	44.9	8
	C	20.2	47.9	5
28 Medium land, Timaru and Waimate downs	A	16.2	45.9	10
	B	43.2	49.8	22
	C	15.5	51.5	12
	* E	15.5	48.1	9
29 Medium land, Waimate plains	A	17.5	48.3	7
	B	46.5	44.1	12
	C	24.0	44.4	8

* E in Timaru-Waimate is: ploughing, one or two tillings only.

skim ploughing is used after the brassica crop. (Note that Table 8 refers to percentage of the area, whereas Table 5 deals with numbers of crops.)

The effect of cultivation pattern on yield (Table 7) was not significant except for the North Canterbury district 21, where the yield was much higher if the number of grubbings after cultivation did not exceed three. There was great variation between the yields of crops within any sub-class, and the standard errors of the average yields were high. Thus, although some of the differences between cultivation patterns appeared large, they did not reach statistical significance.

TABLE 8. PERCENTAGE OF AREAS IN EACH LAND CLASS IN TWO MOST COMMON ROTATIONS FALLING IN CULTIVATION GROUPS

	Rotation	Cultivations				
		A	B	C	D	Other
Light land	1	63	33	4	—	—
	2	8	66	7	3	16
Medium land	1	66	11	12	—	11
	2	18	66	14	1	1
Heavy land	1	75	2	12	—	11
	2	33	40	20	4	3

Key:—

Rotations: 1. Grass, grass.
2. Grass, brassica.

Cultivations: A. Skim ploughing, deep ploughing, grubbing or discing, harrowing and/or rolling.
B. Deep ploughing, up to 3 grubbings, harrowing with or without rolling.
C. Deep ploughing, more than 3 grubbings, harrowing with or without rolling.
D. No ploughing, any number of grubbings, harrowings or rollings.
Other includes unknown.

CONCLUSION

When the list of farms had been prepared and the random sample drawn, the amount of field work required to get useful schedules from 90% of those asked was not excessive. This was achieved with no statutory powers but by personal visits. The amount of sampling done was sufficient to give useful measures of acreages of wheat and yields in relatively small homogeneous areas, but was not sufficient for measuring the effects of cultivation practices on yield within small districts.

CONTROL OF THE CABBAGE APHID (*Brevicoryne brassicae* L.) WITH SOME SYSTEMIC MATERIALS

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(*Received for publication, 10 June 1960*)

Summary

The control of the cabbage aphid on cruciferous seed-crops offers a special field for the aerial application of systemic materials.

In an experiment using Ekatin, Megatox and Metasystox at 4 oz active material per acre, and Lebaycid, Metasystox and Rogor at 8 oz, results were tested by Duncan's test. Megatox, Metasystox (8 oz), Ekatin and Metasystox (4 oz), all gave satisfactory control, in that order of merit. Megatox, however, is not available for commercial use at present in New Zealand.

Introduction

The cabbage aphid problem in Canterbury has been briefly outlined by Lowe (1958). Because of the part played by seed-crops in carrying the overwintering population into the spring period, it is desirable that a reliable form of chemical control be available during the early spring period. The height of the crops during flowering varies from 4–5 ft in rape to 5–9 ft in chou moellier, and precludes the use of ground machines. The application of liquid chemicals, which appears to be the choice of most farmers in New Zealand, from the air, limits the effectiveness of contact materials, since most of the aphids are inaccessible to a method of application giving only top cover. The position is further complicated by the regulations protecting beekeepers in New Zealand, which make it illegal to treat such crops after 1 September except by permit, since after this date flowers begin to be frequented by bees in large numbers. Plants, however, are very variable in time of flowering, and at this date many heads are still enclosed within the leaves, giving aphids adequate protection. For these reasons, a replicated hand trial using some of the newer systemic materials was laid down using a minimum of water as is normal in aerial application methods in this country.

Experimental Methods and Materials

The field chosen for this experiment was a crop of chou moellier sown December 1958, at Charing Cross, near Darfield, Canterbury. Plots were $\frac{1}{2}$ chain square, replicated five times in a randomised block design. Materials were applied with a knapsack sprayer in 20 gal of water per acre, in ideal spraying conditions on 18 August 1959. Untreated control plots were included in the design. The crop was showing some flower-heads, but no colour, and previous sampling at 20-pace intervals on transects across the crop (10 samples) on 15 August 1959 had established the mean aphids per plant as 60, and on 18 August 1959 (30 samples) as 62. These counts, when transformed by the same method of analysis used in dealing statistically with the results of this experiment, give a

weighted mean of 28.9 aphids per plant for this field. Most of the aphids were still enclosed within the crown of the plant at spraying, so that the trial was essentially one of the systemic properties of the materials used.

Table 1 lists the preparations used and their active ingredient dosage per acre.

TABLE 1. SYSTEMIC MATERIALS TESTED

Material	Concentration Used (%)	Active Ingredient Per Acre (oz)
Ekatin	20	4
Lebaycid	50	8
Megatox	15	4
Metasystox	50	4
Metasystox	50	8
Rogor*	40	8
Control		Untreated

* Subsequent chemical analysis of the sample used, which had been under storage since the previous season, when it was supplied as 40%, showed it to be 25%, giving an equivalent dosage of 5 oz active ingredient per acre. This fact should be borne in mind in assessing the results.

RESULTS

Analysis of variance was carried out on counts taken on all plots at 3, 6, and 11 days after spraying. For a few days after spraying there is some difficulty in being sure whether apparently moribund aphids are actually dead, unless a material acts very rapidly. Even with a slower-acting material, however, the effect is apparent at six days. The counts at six and 11 days would normally be regarded for this reason as most fairly assessing the results, but in this case analysis failed to reveal significant count differences between days at the 5% level.

Treatments were significantly different and Duncan's (1955) test showed that Metatox gave the greatest reduction in aphid numbers,

TABLE 2. RESULTS OF TESTS WITH SYSTEMIC MATERIALS

Material	Dosage: (Oz Active Ingred./ Acre)	Mean Log (n + 1)	Equiv. Aphids (Mean Number Per Plant)	Significance* Levels 5%	1%
Megatox	4	.28	0.9	a	A
Metasystox	8	.54	2.5	ab	AB
Ekatin	4	.61	3.1	b	AB
Metasystox	4	.79	5.2	b	BC
Rogor	8	1.06	10.5	c	C
Lebaycid	8	1.45	27.2	d	D
Control		1.46 (s.d. = .091)	27.8	d	D

* Means designated by the same letter are not significantly different on Duncan's test.

but that it did not differ significantly from Metasystox (8 oz) at the 5% level. Ekatin, Metasystox (4 oz) and Rogor were also significantly better than control at the 5% level. At the 1% level, all materials except Lebaycid were better than control.

The results may be conveniently represented in order of effectiveness according to Duncan's method as shown in Table 2, together with the details of differences and equivalent number of aphids.

Conclusions

It is obvious from the results of this trial that there are commercially available several materials which would, by systemic action, give good control of the aphid concerned when applied in a quantity of water as low as 20 gal per acre.

Discussion

In applying these results under practical field conditions it should be noted that some materials used belong to the organophosphorus group, and require certain legal and health precautions to be taken under New Zealand conditions. At the time of this trial, Megatox, the active ingredient in which is the chemical sodium fluoroacetamide, had not been cleared for commercial use in New Zealand pending further information becoming available on its effect on human and stock health. This precludes its use against aphids on crops meantime. Metasystox and Ekatin would therefore be the best materials most readily available for this purpose at present. Each should be used with adequate attention to its respective hazards, as outlined by the New Zealand Department of Health and the Horticulture Division of the New Zealand Department of Agriculture.

Acknowledgments

The author is indebted to Mr C. T. Jessop, Technical Trainee, Entomology Division, Lincoln, for his meticulous assistance in laying down and assessing the trial; to Dr B. I. Hayman, Applied Mathematics Laboratory, Lincoln, for analysing the results; and to the various firms who supplied the commercial materials.

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MANGANESE DEFICIENCY OF WHEAT (*Triticum sativum* L.) ON WAIMAKARIRI SANDY LOAM

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(*Received for publication, 12 October 1960*)

Summary

In 1957 portions of a wheat crop growing on Waimakariri sandy loam at Southbridge developed classical symptoms of manganese deficiency. Plants in pots and in the field, when sprayed with manganese sulphate or chloride, recovered and developed normally.

Manganese contents of soil and plants were within the accepted range for manganese deficiency. Deficiency symptoms developed when the pH of the topsoil was about 7.3; growth was normal when the pH was about 6.9.

The condition was diagnosed as a lime-induced manganese deficiency of wheat growing on a soil of which the manganese content was critically low.

Introduction

Patches of unhealthy plants were observed in early October 1957 in a field of Arawa wheat growing on Waimakariri sandy loam, with ridges of stony sandy loam, in the Southbridge district of Canterbury. The affected plants, which were about nine inches high, showed a mild interveinal chlorosis and moderate stunting, with many leaves folded across their width. These plants were concentrated on the headlands and diagonals of the rectangular field and the patchiness of the occurrence was notable.

No bacterial fungoid diseases were observed in all the affected plants and the following experiments were made to determine whether a nutrient deficiency was the cause of the disorder.

Experimental

Experiment 1

Healthy and unhealthy plants with considerable surrounding soil were removed from the field, grown in pots, and sprayed with 1% solutions of the sulphates of magnesium, manganese, copper, and potash. Pots of both healthy and unhealthy plants were held for observation and comparison.

A slight but definite improvement in the greenness and growth of plants in all treated pots occurred after seven days, but, after 16 days, the plants which had received the manganese sulphate spray were visibly superior in colour and growth to those treated with the other three nutrients, though still slightly inferior to the healthy untreated plants. By this time the untreated plants exhibited classical symptoms of manganese deficiency of wheat as described by Mulder and Gerretsen (1952). The

* Now Chief Soil Conservator, Otago Catchment Board, Dunedin.

plants were stunted, poorly tillered, and yellow, and interveinal chlorosis of older leaves was continuous and complete.

The differences between treated and untreated plants are shown in Fig. 1.

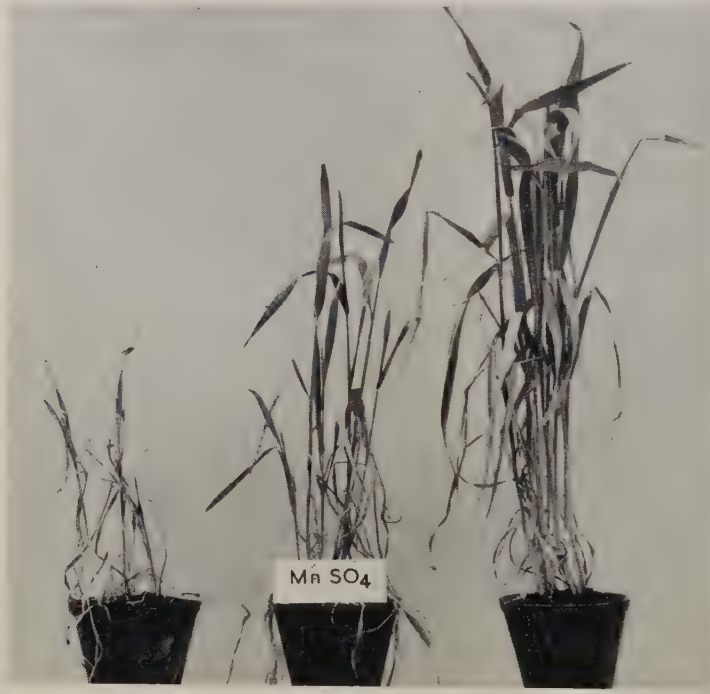

Fig. 1.—Wheat plants showing, from left to right: affected plant; plant treated with $MnSO_4$; normal healthy plant.

The appearance of mature plants in the various treatments is shown in Fig. 2.

Experiment 2

Square yard plots located at random in the affected patches of the wheat field were sprayed on 31 October 1957 with only sufficient material to cover the foliage. The treatments were similar to those used with the pot trial.

Only those plants which received $MnSO_4$ responded, grew satisfactorily, and produced a reasonable seed crop. The rest became smothered by weeds, particularly *Vicia sativa* and *Cirsium arvense*, and produced very few flowering tillers and little seed.

Experiment 3

A randomised block experiment of six replications of four treatments was commenced on 11 November 1957 on the affected portions of the wheat crop. Treatments were:

TABLE 1. RESULTS FROM MANGANESE TREATMENTS IN EXPERIMENT 3

Treatment	Total Yield g/Plot	Duncan's Test 5%	Duncan's Test 1%	Grain Yield g/Plot	Duncan's Test 5%	Duncan's Test 1%	1,000 Grain Weight g	Duncan's Test 5%	Sediment-ation Score	Duncan's Test
$MnCl_2$	3,220	ab	A	517	ab	A	36.4	ab	25.2	b
$MnSO_4$	4,090	a	A	682	a	A	38.7	a	25.8	ab
$CaSO_4$	2,500	b	AB	458	b	AB	38.1	a	26.1	ab
Control	1,230	c	B	214	c	B	34.8	b	29.5	a
C.V.	36%			33%			6%		11%	

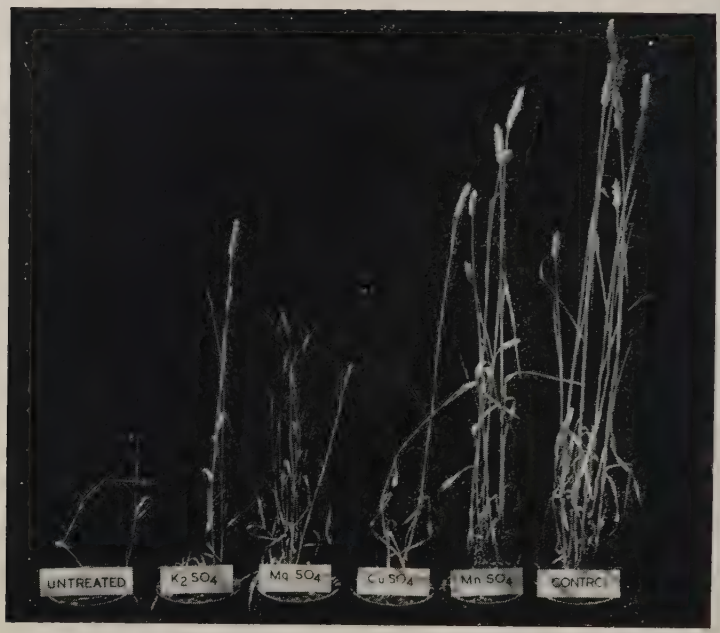

Fig. 2.—Mature wheat plants from treatments as shown. The plant labelled "Control" is a healthy untreated plant.

(1) Control—no treatment.

(2) Manganese chloride spray.
(3) Manganese sulphate spray.
} Supplying manganese at 20 lb per acre at approximately 1 oz per gallon.

(4) Calcium sulphate powder—broadcast at 100 lb per acre.

The two manganese treatments supplied equal amounts of manganese, the chloride and gypsum being included to determine whether the response was due to sulphate or manganese or to sulphate affecting the uptake of manganese. The plots were 20 ft by 7 rows, with the rows 7 in. apart; but the affected portions of the field were so variable that it was impossible to select uniform blocks of affected plants.

On 10 February 1958 the plots were harvested by pulling. The sheaves were air-dried and weighed and samples taken for determination of manganese content. They were then threshed and the weight of grain determined.

Results

Total and Grain Yields

The mean total yields and grain yield from treatments harvested on 10 February 1958 are shown in Table 1.

Each treatment yielded significantly more in total and in grain than the control; the calcium sulphate treatment yielded more at the 5%

probability level and the remaining two treatments at the 1% level. The absence of a significant difference between the chloride and the sulphate of manganese suggests, as did the earlier experimental results, that sulphur was not limiting. The highest yields were given by manganese sulphate.

Grain Weight and Quality

The mean thousand-grain weights and sedimentation scores are included in Table 1. The Zeleny sedimentation test (Pinckney, Greenaway, and Zeleny 1957) measures differences in the quantity and quality of the gluten in wheat, and hence gives an indication of baking quality.

There were no significant differences between the average grain weights of the three treatments, but both sulphate treatments produced grain significantly heavier than the control.

The average sedimentation score over the three treatments was significantly lower than the average from the control plots. The response to manganese chloride was significant, and the response to manganese sulphate was close to significance. The grain from the control plots was somewhat shrivelled, and would be expected to yield flour of higher baking quality.

Plant Analyses

Results of the plant analyses on samples taken at harvest and the total yield per plot are given in Table 2.

TABLE 2. MANGANESE CONTENT OF WHEAT PLANTS AND TOTAL YIELDS FROM PLOTS HARVESTED ON 10 FEBRUARY 1958

Treatment	Yield D.M., g/Plot	Manganese Content P.P.M. On D.M. Basis
$MnCl_2$	3,220	25.5
$MnSO_4$	4,090	22.7
$CaSO_4$	2,500	10.7
Control	1,230	11.0

Plants from the manganese treatments had about twice as much manganese per unit of dry weight as the control and about seven times as much per plant. The smaller but still significant yield response to calcium sulphate is of interest since this treatment did not result in any increase in the manganese content. Total manganese uptake was, however, doubled, suggesting that the sulphate increased the availability of manganese. This increase in yield without a simultaneous increase of element content is not unusual in cases of deficiency when small additions of the element concerned are made.

PLANT AND SOIL ANALYSES

Samples of poor and apparently healthy plants were taken in November from areas adjacent to the plots in Experiment 3. Dry

matter per plant and manganese contents were measured. No difference was found in manganese content between poor and good plants, six samples of each giving results ranging from 8.1–14.0 p.p.m. for poor plants and from 8.1–13.8 p.p.m. for good plants. Dry matter yields, however, at this stage were very different, being 4.3 g/plant for good plants (mean of 55) and 0.8 g/plant for poor plants (mean of 133). Clearly the total uptake of manganese was markedly different in the two cases.

Soil samples were also taken at this time and tested for pH and exchangeable and easily reducible manganese. Conventional analytical procedures were used. The results of these analyses are shown in Table 3.

TABLE 3. Soil Analyses

Site	Plant Growth	pH		Manganese — P.P.M.	
		0–3 in.	3–6 in.	Exchangeable	Reducible
1	Poor	7.4	7.2	1.1	10.2
2	,,	7.2	7.4	1.2	7.4
3	,,	7.2	7.0	1.6	7.6
4	,,	7.3	7.2	1.0	13.0
5	,,	7.3	7.4	1.1	12.2
6	,,	7.3	7.2	1.6	12.6
1	Good	6.9	7.1	1.5	12.3
4	,,	6.9	7.0	1.1	11.0
5	,,	6.9	7.1	1.3	14.3

As in the case of the plant analyses, the results for manganese show little difference between areas of good and poor growth. It is noteworthy, however, that the pHs in the 0–3 in. zone of the poor areas were consistently higher—0.3 to 0.5 pH higher.

These results suggest that this crop was in a state of mild deficiency. Goodall and Gregory (1947) quote (p.29) deficient wheat plants as having 4–10 p.p.m. manganese, and healthy plants 16–28 p.p.m. Mulder and Gerretsen (1952), for winter wheat analysed in spring, quote 20.3 and 22.5 p.p.m. as deficiency levels, and 34.5 and 48.5 p.p.m. as sufficient for normal growth. Nicholas (1949) reported wheat showing a mild deficiency on a soil with pH 7.1, exchangeable manganese 1.1 p.p.m., and easily reducible manganese 31 p.p.m. The manganese content of the wheat leaves was 14 p.p.m. In a paper published in 1935 Leeper suggests that soils may be deficient if they contain less than 15 p.p.m. of manganese. (He used ammonium acetate and quinol—the method used in this study).

Discussion

These results show that the condition described in wheat resulted from mild manganese deficiency. Lobb (1959) has suggested that manganese deficiency of cereals may occur in Canterbury, but no experimental results have been published to confirm this suggestion. Lynch (1954) concluded that there was little or no evidence of manganese

deficiency of pastures in New Zealand; in six trials no response to manganese salts had been obtained. Up to now measured and recorded responses to manganese in New Zealand appear to have been restricted to fruit crops, as summarised by Bollard (1955).

In the field, the patchiness of the affected areas, the visual symptoms, and the partial recovery of the less seriously affected plants, all conform to the reports on manganese deficiency by other workers—Carne (1927) and Teakle and Wild (1940). Manganese content of both plants and soil fell within the range for deficiency reported by many workers. The initial response to all four sulphates in the first experiment and to calcium sulphate in Experiment 3 is thought to be caused by the effect of sulphate increasing the availability of manganese, not by correction of a sulphur deficiency.

The history of the field, close observation of the development of the condition, and the established experimental evidence, all suggest the following aetiology of the deficiency.

This soil is critically low in available manganese. Where generous liming has been carried out, or where—owing to the prevailing method of applying lime—heavy applications have been made to the diagonals or headlands of a field, the pH has been raised, with a resultant depression of available manganese. In such soils, it is likely that the availability of manganese would be still further reduced where organic matter levels have risen following high-producing pastures. The wheat retained a normal healthy appearance from germination in June until about mid-September, indicating that available manganese was adequate for the low rate of winter growth. The advent of spring provided conditions suitable for rapid growth of the crop but presumably not for a sufficiently rapid increase in the production of available manganese, which lagged temporarily behind requirements in some parts of the field and permanently in others. In all affected areas the deficiency symptoms developed quickly, but in many areas they remained only on the basal leaves. With warmer, drier weather, new growth developed normally on those plants previously affected and situated on the outside edges of the affected patches. There was a consequent substantial reduction in the size of affected patches. Severe deficiency persisted, however, on the diagonals and headlands where double liming had previously occurred.

The condition could, consequently, be diagnosed as a lime-induced manganese deficiency of a soil in which this element was at a threshold level of availability. The possibility that the deficiency was caused by some other combination of circumstances is remote but cannot entirely be discounted.

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VITREOUS GRAIN IN WHEAT AND THE RELATION OF SEDIMENTATION AND BAKING SCORES

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Summary

Samples of Cross 7, Aotea, and Arawa wheat from 19 regional trials were analysed to study varietal differences in the relation of sedimentation test scores to baking test scores, and the associations of these differences and scores with variations in vitreousness, total nitrogen content, and yield.

There were significant differences between the varieties in all of these characteristics. Prediction of baking score from sedimentation score was satisfactory for Arawa, and for autumn-sown Cross 7, but not for Aotea. There were no consistent relationships between vitreousness or yield and the other characteristics. It is suggested, however, that varieties, or particular samples of a variety, with starchy grain have sedimentation scores which are high in relation to baking score and total nitrogen content.

The sedimentation score had a higher correlation with baking score than the specific sedimentation value (the ratio of sedimentation score to nitrogen content).

Introduction

The modified Zeleny sedimentation test (Pinckney, Greenaway, and Zeleny 1957) is used as an empirical measure of the quantity and quality of gluten in wheat, and as an indicator of baking quality. It was found (Copp and Wright 1957) from the results of trials in two seasons that the prediction of baking score from sedimentation score was satisfactory for autumn-sown wheat, provided separate equations were derived for each variety. For spring-sown wheat, however, no association between the scores was established, and it appeared that this might have been a consequence of variation in yield.

Variation in the results of quality tests may be related to differences in vitreousness (Schollenberger and Coleman 1926; Pinckney, Greenaway, and Zeleny 1957). As no information on vitreousness was available for the principal New Zealand wheat varieties, estimates have been obtained from a series of samples for comparison with the results of standard quality tests.

The sedimentation test is used at the Crop Research Division as an aid to selection in early-generation hybrids (Copp 1956), and in 1959 it was used by the Wheat Research Institute, Christchurch, to screen all lines of milling wheat offered for sale. The determination of vitreousness in grain samples was studied as a potential aid to the prediction of baking score from sedimentation score.

Material and Methods

A total of 57 grain samples of Cross 7, Aotea, and Arawa was obtained from 19 co-operative variety trials harvested in 1956. Eight trials, in Marlborough and Canterbury, were autumn-sown, and all wheat-growing areas of the South Island were represented in the spring-sown trials.

In 1955 the weather was favourable for sowing and early growth. Rainfall was below average, however, and in late spring and summer conditions were very dry. In the four months from September to December most of the trial areas in Marlborough and Canterbury received less than seven inches of rain, and in South Otago and Southland the rainfall was from eight to ten inches. Stern and Wright (1956) calculated potential evapotranspiration from evaporation records from the Canterbury Agricultural College, Lincoln, and concluded that, over much of North Canterbury, there was not enough moisture for full growth at the end of December, even on heavy soils. In January 1956 temperatures up to 100°F were recorded. Crops ripened early, and in Canterbury most of the wheat had been harvested by the end of January. Yields in general were below average, particularly on light land.

For the determination of baking quality, loaves were baked from 125 g of a 72%-extraction flour, with appropriate improvers, and assessed for loaf volume, crumb colour, and crumb texture. A score of 36 represents a good loaf, 40 an excellent loaf.

Sedimentation score was determined on 2 g of the 12%-extraction flour obtained from 20 g of wheat ground in a "C. and N. Junior" laboratory mill.

Estimates of vitreosity were obtained by examining two sub-samples of 40 to 50 grains in cross-section. The individual percentages of completely vitreous grains were transformed (Stevens 1953) and averaged for statistical analysis. Evidence of absence of bias in the determinations was obtained by comparing two estimates of the error of determination. The experimental variance of a single transformed determination was 21.68, and the expected variance was 1,000/46.411, or 21.55, the harmonic mean number of grains observed being 46.411. There is therefore no evidence of bias.

Nitrogen determinations by the Kjeldahl method were made on ground whole-grain samples, and on the starchy and vitreous fractions from three samples of each variety.

Results—Single Characters

In Table 1 are the average values of each variable for the three varieties in each season of sowing, and the season-of-sowing averages.

Mean squares and related statistics from analyses of variance are presented in Table 2. Mean squares for trial differences have not been included. For each character the trial-to-trial variation was divided into three parts, to provide comparisons both between and within the

TABLE 1. VARIETY AND SEASON AVERAGES IN QUALITY CHARACTERS AND YIELD

	Baking Score	Sedimentation	Vitreosity %	Vitreosity θ	Total N%	Yield (bus. p. acre)
Cross 7 a.s.*	36.8	25.5	56.5	54.1	1.92	50.0
s.s.†	37.5	43.1	43.0	45.5	2.06	49.9
Aotea a.s.	36.1	22.9	47.4	48.4	1.83	62.9
s.s.	36.8	32.8	31.2	37.8	1.89	60.3
Arawa a.s.	31.9	32.2	21.6	30.9	1.90	63.9
s.s.	30.3	45.7	11.7	22.4	2.04	55.5
Approx. S.E.	0.5	2.1	—	2.6	0.03	1.5
All varieties:						
Autumn-sown	34.92	26.9	41.3	44.5	1.883	58.9
Spring-sown	34.88	40.5	27.5	35.2	1.998	55.2
Approx. S.E.	0.28	1.3	—	1.5	0.015	0.9

* Autumn-sown.
† Spring-sown.

two seasons of sowing. The variations in vitreosity between autumn-sown trials, and the seasonal differences in yield, were highly significant, and there was no difference between autumn- and spring-sown trials in average baking score. The remaining 12 comparisons were all very highly significant.

TABLE 2. ANALYSES OF VARIANCE

	d.f.	Baking Score	Sedimentation	Vitreosity θ	Nitrogen %	Yield
Mean squares						
Variety:						
Aotea v. Arawa	1	295.68	1,239.18	2,528.95	0.1369	53.29
Cross 7 v. others	1	152.84	22.82	2,870.04	0.0780	1,327.38
Var. x a.s. v. s.s.						
Aotea v. Arawa	1	12.21*	28.93	9.69	0.0172	78.39
Cross 7 v. others	1	4.83	106.78	2.81	0.0042	90.72*
Error	34†	2.13	44.07	65.21	0.0060	20.67
Standard Devn.		1.46	6.64	8.08	0.078	4.55
Coeff. of Variation		4.2%	19.1%	20.7%	4.0%	8.0%
Components of Variance (%)						
Variety	2	60	17	37	12	13
Trials	18	27	59	47	73	78
Error	36†	13	24	16	15	9

* Significant at 5% level (for variety differences see text).
† One less degree of freedom for Error in sedimentation score (a missing value).

The components of variance in Table 2 were derived from simple analyses of variance, as shown by the numbers of degrees of freedom. In four of the characters the greatest proportion of the variance was due to trial differences.

Baking Score

In general, Cross 7 is slightly better in baking quality than Aotea, though the difference was not significant in the present data. The baking quality of Arawa was below that of the other two varieties to a highly significant degree, the difference being greater in spring-sown trials. The poor quality of Arawa in spring-sown trials was not associated with higher yields, nor with lower nitrogen content or sedimentation score, and it was not confined to trials affected by drought.

The trial averages in baking score varied from 30 to 38, and no adequate explanation of the trial differences was found in terms of cropping history, soil fertility, or drought.

Sedimentation Score

Interactions of variety and sowing time were not significant. The average score for Aotea was significantly below that for Cross 7, and below that for Arawa to a highly significant degree. Individual determinations ranged from 7 to 63, and trial averages from 14 to 56.

Vitreousness

Differences between varieties for the times of sowing were similar to one another. The difference between Cross 7 and Aotea was significant, and that between Aotea and Arawa was very highly significant.

In the nine samples which were subdivided into vitreous and starchy fractions, the nitrogen content of the vitreous grains was considerably higher than that of the starchy fractions, averaging 2.01% compared with 1.74%, a highly significant difference.

The vitreousness of samples from the trials sown after potato crops was relatively low, although the nitrogen content was higher than average. In general, vitreosities on the more fertile soils were relatively high in autumn-sown, and low in spring-sown, trials. Trial averages varied from 3% to 69% of vitreous grain, and, because of the dry conditions and early harvest, vitreosities were probably higher than in most seasons (cf. Freitas 1953; Paquet 1956).

Total Nitrogen Content

Varietal differences were similar in autumn- and spring-sown trials, Aotea having a significantly lower average than Cross 7 and Arawa. Trial averages ranged from 1.5% to 2.3%. Nitrogen content may have been higher than in most seasons, as found with barley (Stern and Wright 1956).

Yield

The differences in yield between the varieties were similar to those obtained in other seasons. The average yields for trials varied from 28 to 82 bushels per acre, and the effects of drought were highly significant. No effect of previous cropping was established.

BIVARIATE ANALYSIS

Sums of products were calculated corresponding to the sums of squares required for the above analyses, and various sets of correlation coefficients, and linear and multiple regression equations, were derived.

Correlation coefficients are presented in Table 3, in which, for convenience, coefficients less than one third of the size required for significance have been omitted. The "within trials" correlations are independent of variety differences and of variety by season-of-sowing interactions. The evidence from autumn-sown trials does not show any tendency for yield and quality to be inversely related; there were no associations of quality differences with variation in yield from trial to trial. Within the spring-sown trials the negative correlation of yield with total nitrogen content is significant, and that with baking score approaches significance.

TABLE 3. CORRELATION COEFFICIENTS

	Total	Total Within Varieties	Between Trials		Within Trials	
			Autumn-Sown	Spring-Sown	Autumn-Sown	Spring-Sown
Baking score and sedimentation	0.10	0.44**	0.88**	0.42	0.27	0.26
Baking score and vitreosity	0.44**	0.10	0.27	—	—	0.36
Baking score and total nitrogen	0.35**	0.63**	0.92**	0.56	0.69**	0.50*
Baking score and yield	—	0.10	—	—	—	−0.39
Sedimentation and vitreosity	−0.15	—	0.32	0.34	−0.47	−0.22
Sedimentation and total nitrogen	0.75**	0.74**	0.75*	0.91**	—	0.43
Sedimentation and yield	—	—	0.30	—	—	—
Vitreosity and total nitrogen	—	—	—	—	0.32	0.36
Vitreosity and yield	—	—	0.50	−0.31	—	—
Total nitrogen and yield	−0.16	−0.10	—	—	0.28	−0.53*
Degrees of freedom	55†	53†	6	9	13	19†
5% sign. level	0.26	0.27	0.71	0.60	0.51	0.43

† One less degree of freedom for correlations with sedimentation score.

The inter-relations of baking score, nitrogen content, and sedimentation score provide nearly all the significant correlations. When variety and trial differences were eliminated, total nitrogen was closely associated with baking quality, but the correlation of sedimentation score with baking score and with nitrogen was confined to that produced by trial-to-trial variation.

Some of the correlations of vitreosity may be important. The highly significant "total" correlation of vitreosity with baking score is produced by variety differences: Cross 7 is the highest and Arawa the lowest in both characteristics. With variety, season, and trial effects removed, high vitreosity was associated with low sedimentation score,

although all the other correlations between quality factors, including those omitted from the table, were positive. The within-trial partial correlations of vitreosity and sedimentation, adjusted to constant nitrogen content, were —0.55 (significant) and —0.44.

Sets of correlation coefficients were calculated for each variety, for the two groups of trials. They are not independent of those in Table 3. The correlation between nitrogen and sedimentation score was lowest in Aotea, in both groups of trials; and, although the relation of baking score and nitrogen was significant for each variety when autumn-sown, and also for spring-sown Arawa, the relation of baking score and sedimentation was not significant for autumn-sown Aotea. In the spring-sown trials there was a poor correlation between sedimentation score and baking score for Cross 7 and Aotea.

It has been suggested (Schaefer 1957) that a "specific sedimentation value", defined as the ratio of sedimentation score to total protein or nitrogen, may be a more useful index of quality than the sedimentation score. In the present material this ratio was calculated for all samples, but it was not found to be useful. The ratio was higher for spring- than for autumn-sown trials, although there was no difference in baking quality, and it was highest for Arawa, the variety with the lowest quality. Correlation coefficients of the ratio with baking score, calculated for each variety from the spring-sown trials, were much lower than those for sedimentation score with baking score.

Multivariate Analysis

Multiple regression equations were derived from the residual sums of squares and products for autumn and spring data, separately and together, to study the joint relations of the other characteristics to baking score. The multiple correlation coefficients corresponding to the three regressions were 0.712, 0.629 and 0.592 respectively; only the third, which has the most degrees of freedom, is significant.

In autumn-sown trials the other variables do not contribute additional information to the relation of nitrogen to baking score (compare 0.712 with the simple correlation 0.69, in Table 3). In the spring-sown trials, however, nitrogen apparently made no contribution to the multiple regression, although it had the highest correlation with baking score (0.50). The regression with nitrogen removed was significant, but none of the multiple regressions showed an appreciable increase in the accuracy of predicting baking score, compared with linear regressions on nitrogen content.

Discussion

The detailed analysis of quality determinations on 57 samples of wheat has yielded few useful results. The trials covered a wide range of conditions, which affected in different ways the measures of quality of the three varieties. Accurate estimates of the relations between the measures of quality were not obtained, but many difficulties are involved in obtaining more extensive or more precise information. To make

varietal comparisons with precision it is necessary to grow replicated trials or else collect very large numbers of samples, and only a limited number of trials or samples can be handled in one season. Furthermore, the combination of results of quality tests from different seasons would not be valid.

The results from the 1955-56 trials, used in this paper, were of particular value because of the number of spring-sown trials included. In most seasons it is not practicable to sow a special series of these trials.

Differences between varieties have been found in each character studied. The behaviour of Aotea is of particular interest, since, owing to its good agronomic characters and high yield, it has recently become the most important variety in New Zealand. Aotea is relatively low in total nitrogen and in sedimentation score, but not in baking quality. Arawa is higher in nitrogen content and much higher in sedimentation score, and low in baking quality. A study of the constituent proteins of the gluten of Aotea and Arawa might lead to an understanding of the difference in their behaviour in the sedimentation test.

The relations of vitreosity to other characteristics are of interest, though their significance has not been established. The only negative correlations in Table 3 are some of those with yield, and some of those between vitreosity and sedimentation score. The combined "within trials" correlation between vitreosity and sedimentation is —0.339, and is significant; and the partial correlation, with differences in total nitrogen removed, is also negative and significant. The other quality correlations were all positive, and an explanation for the negative correlations may follow from a study of dissected grains by O'Brien, Moss, and Debrett (1957). In starchy samples, which have low total nitrogen and produce a low-quality 72% extraction flour, the 12% extraction flour used for the sedimentation test contains a high proportion of the peripheral endosperm. This is higher in nitrogen than is the rest of the endosperm, particularly in starchy grains, and the flour would have a relatively high nitrogen content. The effect would only be detected in the present data in the residual (within-trial) correlations, being overshadowed by the large over-all differences from trial to trial; but a test of the soundness of this explanation would be given by determining the nitrogen content of whole grains, 72% flour, and sedimentation-test flour, for a number of starchy and vitreous samples of wheat. The suggested fractionation may explain the high sedimentation score of Arawa.

Although the present study, based on only three varieties and on samples from only one season, may be considered to be of limited value, the differences between the varieties, and particularly the varietal differences in the relationships between the characteristics investigated, have been shown to be important; generalisations referring to other varieties and seasons must be made with caution. While it has not been established that the vitreousness of a sample has a strong effect on the results of the sedimentation test, the effect is not negligible, and it is possible that a modification of the method of preparing flour samples

for the test would improve the consistency of results. Evidence has recently been obtained that results derived from some varieties are more reliable if the finest flour is sieved out and discarded.

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